Ten Things You Should Know About HALT & HASS

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SUMMARY & CONCLUSIONS

HALT & HASS (Highly Accelerated Life Testing and Highly Accelerated Stress Screening) are relatively new product test methods. They are used on many products worldwide, from consumer products to aerospace equipment. HALT is used during design and HASS during production. Both these methods are fundamentally different to conventional test methods. An objective of HALT is to intentionally cause failure to occur during test, and not to demonstrate compliance with development specifications.

It is therefore often difficult for engineers, and especially technical management, to fully understand the principles of HALT & HASS. This paper starts with a brief introduction on reliability engineering, and continues with an overview of HALT & HASS. Ten aspects, considered to be essential to understand HALT & HASS, are discussed. The paper is intended as management overview to facilitate successful HALT & HASS implementation.

1 WHAT IS RELIABILITY?

> "All failures in electronic equipment can be attributed to a traceable and preventable cause, and may not be satisfactorily explained as the manifestation of some statistical inevitability."
>
> Norman Pascoe [1]

This statement refers to two fundamental concepts in reliability engineering. Firstly, failures are caused, and secondly, failures can be prevented. Philip Crosby [2] correctly stated: "All non-conformances are caused. Anything that is caused can be prevented."

Based on these fundamental concepts, and applying common sense to real-life experience, reliability and reliability engineering can be defined as follows [3]:

- Reliability is the absence of failures.
- Reliability engineering is the management and engineering discipline that prevents the creation of failures.

These definitions imply that a product is reliable if it does not fail, and that this failure-free state can only be achieved if failure is prevented from occurring. What is required to prevent failures? Firstly, engineering knowledge to understand the applicable failure mechanisms, and secondly, management commitment to mitigate or eliminate them. Proactive prevention of failure should be the primary focus of reliability engineering, and not reactive failure management or failure correction. Also, the goal of reliability engineering should definitely not be to "generate an accurate reliability number for the item" [4].

These definitions also imply that failures are created, primarily due to errors made by people such as design and production personnel [5]. Products very seldom fail due to part failure, but often fail due to incorrect application and integration of those parts. Figure 1 shows a typical product development process, with emphasis on design and production verification [3]. The iterative nature of product development (including reliability engineering) is evident. 'Analysis' and 'test' are the two primary verification methods used in engineering. Many reliability engineering tools and techniques are used for this purpose, including HALT & HASS (Highly Accelerated Life Testing and Highly Accelerated Stress Screening).

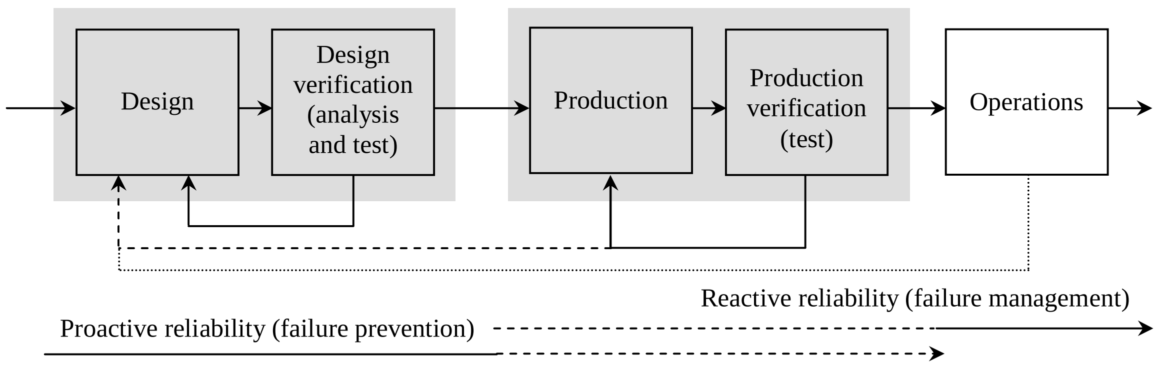

Figure 1 - Design and production verification

2 *WHAT IS HALT & HASS?*

During HALT, thermal stress and vibration stress (as well as any other relevant stress) are applied in a step-stress test until an abnormality in operation (i.e. failure mode) is observed. This may be an operational limit or a destruct limit for the specific stress condition. The product should be powered-up (where applicable), and suitable test equipment used to detect when the abnormality occurs. This failure mode is then considered an opportunity for a design or process improvement, and is analyzed to determine its root cause. Provided that the design or production team is successful in implementing corrective action, product reliability should increase.

HALT & HASS require the use of special environmental test chambers to subject development or production units to stresses exceeding product specification levels. Typical HALT & HASS chambers provide simultaneous multi-axes broadband vibration and rapid thermal cycling.

HALT can be performed using either a Classical HALT process, or by using a Rapid HALT test profile. During Classical HALT, thermal and vibration stress conditions are first applied individually, and finally combined:

- Cold step stress
- Hot step stress
- Rapid thermal cycling
- Random vibration
- Combined thermal cycling and random vibration

Figure 2 shows a step-stress test to determine the lower operational (LOL) and destruct (LDL) limits for temperature, and Figure 3 shows the upper operational (UOL) and destruct (UDL) limits for temperature (and vibration).

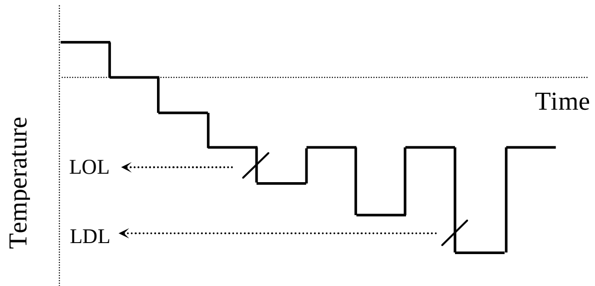

Figure 2 - Lower operational and destruct limits

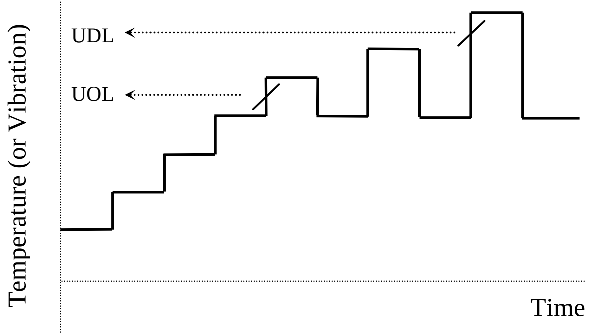

Figure 3 - Upper operational and destruct limits

Determination of operational and destruct limits for temperature and vibration is an important part of HALT. Some companies do not test to destruction due to the high cost of test units (e.g. aerospace products). It should be noted that some engineers incorrectly think that HALT only consists of determination of operational and destruct limits. However, operating margins are important indicators of product robustness (and therefore reliability). Figure 4 shows the operating and destruct margins relative to the product specification levels.

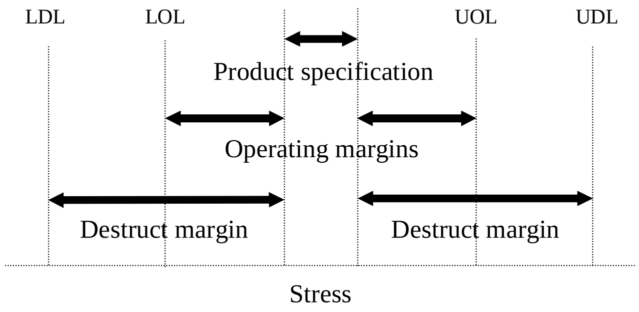

Figure 4 - Operating and destruct margins

Rapid thermal cycling, shown in Figure 5, consists of a few (typically four or five) thermal cycles within the operating range (temperature limits are set at 5°C or 10°C less that the observed operational limits).

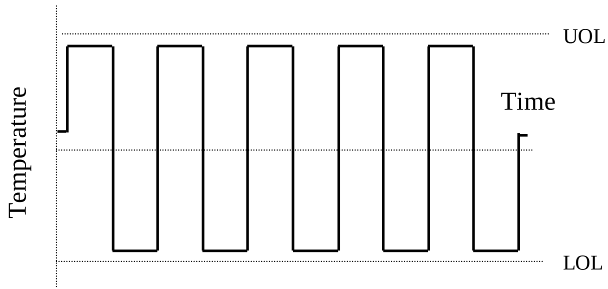

Figure 5 - Rapid thermal cycling

The final step of Classical HALT is to combine rapid thermal cycling with random vibration, as shown in Figure 6. Once again, a few thermal cycles are used while random vibration is step-wise increased in equal steps. The upper vibration operational limit is used to determine equal vibration steps.

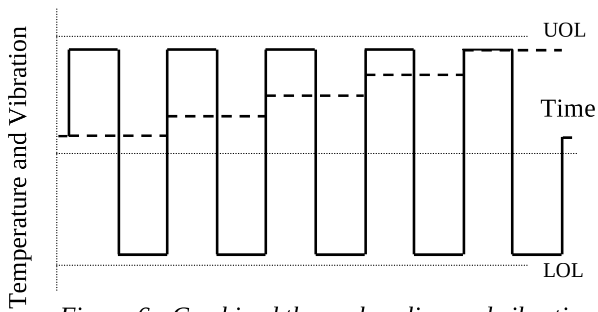

Figure 6 - Combined thermal cycling and vibration

The alternative method to perform HALT is to use Rapid HALT, which combines rapid thermal cycling and random vibration by progressively increasing both stress conditions as shown in Figure 7. Both approaches to HALT may identify the same design weaknesses. However, it may be more difficult to perform failure analysis (i.e. root cause analysis) when using Rapid HALT than using Classical HALT.

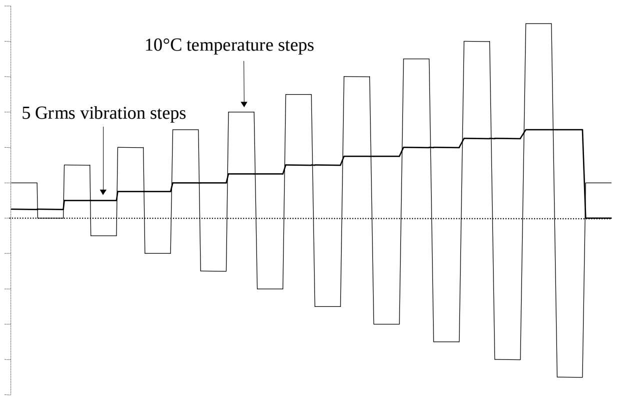

Figure 7 – Rapid HALT profile

The dwell time (at individual high and low temperatures) is the same for both Classical HALT and Rapid HALT, and is typically between 10 and 30 minutes. The dwell time is determined by the time required for the product to stabilize at the specific temperature (i.e. a function of thermal mass), and the time required to perform test diagnostics (i.e. execution of the test procedure).

3 TEN THINGS YOU SHOULD KNOW ABOUT HALT & HASS

3.1 HALT & HASS should be used with other reliability engineering tools

HALT & HASS are not the alpha and omega in reliability engineering, and should not be used to replace other powerful reliability engineering tools. Rather, HALT & HASS should complement them. Generally speaking, reliability engineering analyses can be divided into two groups:

- Engineering analyses (e.g. derating analysis, thermal analysis, finite element analysis, etc.)
- Failure analyses (e.g. FMEA (Failure Mode and Effects Analysis), FTA (Fault Tree Analysis), etc.)

For example, one of the objectives of a design FMEA is to recommend (during design and development) corrective actions to mitigate or eliminate the consequences of unacceptable failure modes. This is done using an analysis process where criticality (i.e. severity and probability of occurrence) of all potential failure modes is determined and ranked. During analysis, the FMEA team uses product and field environment knowledge as well as prior experience to identify 'anticipated' failure modes.

However, when HALT is performed, the design team no longer 'thinks' in terms of potential failure modes, but they 'observe' actual failure modes. Given this similarity between the two approaches, it is not surprising that a design FMEA is an excellent tool to plan for the execution of HALT. Failure modes identified in HALT may in many cases correspond with failure modes identified in a properly executed design FMEA (especially failure modes with high probability of failure).

It is also interesting to note differences between HALT and part derating. A fundamental concept in reliability engineering is that 'load' should never exceed 'strength'. When electronic part derating is used, the expected 'load' for the part is calculated, and an appropriate 'strength' for that part is then selected. 'Load' in this case may be voltage, current, power, junction temperature, etc. The percentage derating to be used can be found using industry standard derating guidelines. However, these guidelines are primarily based on predicted failure rates (e.g. the Arrhenius equation used as relationship between failure rate and temperature), which may be totally erroneous and misleading [3].

On the other hand, during HALT, the 'load' is increased (and 'strength' simultaneously reduced in some instances) until failure occurs, and then the designer can increase 'strength' by selecting another part or by changing the design. This process is based on the actual test evidence, and is not based on assumptions about the strength of the part.

3.2 HALT & HASS are both processes

Many engineers incorrectly think that HALT & HASS are 'tests'. These are not tests, but both are processes. A product cannot 'pass' or 'fail' HALT or HASS. The HALT process should be integrated into design and development, and the HASS process should be integrated into production.

HALT is not 'success testing' where compliance with development specifications is demonstrated. HALT is therefore not compliance testing, nor is it qualification testing. HALT is 'failure testing', or 'discovery testing' where opportunities for improvement are identified. HALT does not measure or predict reliability, but it can certainly help to improve reliability. HALT cannot be described in a test procedure, since the actual failure modes observed during test will guide the HALT process. A typical HALT process consists of at least the following four steps [6]:

- Precipitation
  (change product flaw from latent to patent)
- Detection (observe that abnormality exists)
- Failure analysis (determine root cause of failure)
- Corrective action (design or process change to eliminate cause of failure)

Precipitation, detection and corrective action are relatively easy steps to perform, but failure analysis is generally the most difficult step. Failure analysis (including root cause analysis) usually requires in-depth engineering knowledge of part failure mechanisms.

3.3 HALT & HASS should focus on failure modes

When performing HALT, one should never focus on the applied stress conditions. The stress (or overstress) is only a means to identify an improvement opportunity.

The failure modes observed are based on actual part (electrical and mechanical) strength, parameter variations, production quality, etc. Some engineers argue against using vibration as stress condition for products not exposed to vibration in the field environment. However, due to the 'crossover effect' shown in Figure 8, vibration during HALT may be used to identify the same failure mode that thermal cycling will expose in the field environment [7].

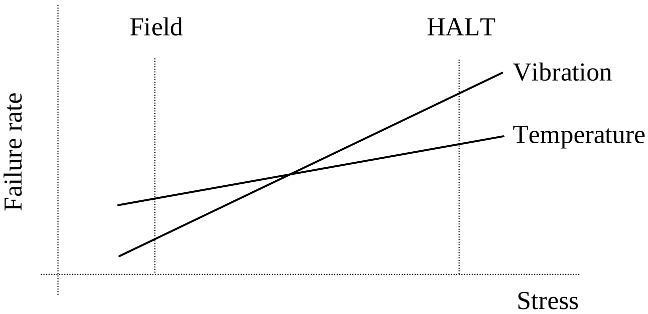

Figure 8 - Crossover effect

3.4 HALT & HASS require failure detection

Both HALT & HASS require that abnormalities in operation be detectable, either visually or preferably by some electrical test. For this purpose, BITE (Built In Test Equipment) or external test equipment designed for production acceptance testing can be used. However, it is important to ensure that a high percentage of failure modes can be detected. Without high test coverage, an abnormality may occur without being detected, and will obviously not be considered for further failure analysis and corrective action.

During HALT & HASS, a high level of random vibration is frequently used for failure precipitation, but a low level may be required for detection. This is especially true in the case of intermittent failure modes, which may only be detectable using tickle vibration. Modulated excitation is a method to search for abnormalities that require a specific combination of thermal and vibration to be detectable [7]. Figure 9 shows modulated excitation as two-dimensional space consisting of temperature and vibration as stress conditions.

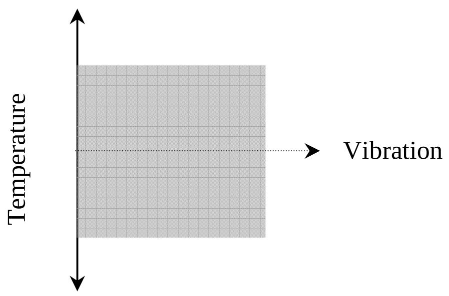

Figure 9 - Modulated excitation

Modulated excitation is considered an excellent method to diagnose field failure modes that are difficult to reproduce in a laboratory environment (i.e. 'no fault found' problems) [8].

3.5 HALT is a prerequisite for HASS

Production screening is performed using a HASS profile derived from the HALT results. This means that HASS should never be used if HALT has not been performed first. It also means that an individual HASS profile should be developed for every product (i.e. HASS profiles are product specific).

During the HALT process, operational limits (and sometimes destruct limits) are identified, and used as inputs to the HASS profile. If the product has limited operating margins, the design has to be improved before implementation of HASS.

During HASS, both precipitation and detection screens may be required. Precipitation is used to change a product flaw from latent to patent (if it exists), and detection is used to observe an abnormality (if it occurs). Precipitation stress levels may be outside the operating range (as shown in Figure 10), but many organizations prefer to limit precipitation screen stress levels to about 80% of the operating range. If the precipitation screen is outside of the operating range, a detection screen is used to detect if any abnormalities have occurred (because failures occurring outside the operating range can obviously not be detected). HASS can be used on all production units, or on a sampling basis (depending primarily on production volumes and the type of product).

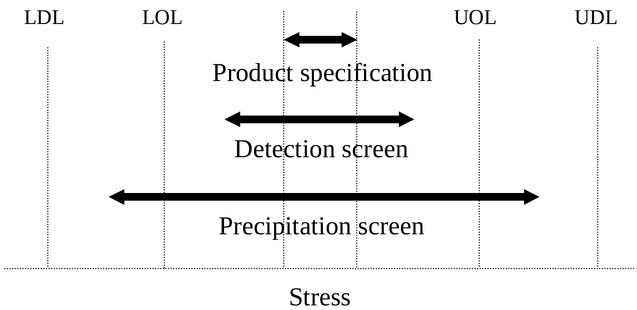

Figure 10 - Precipitation and detection screens

3.6 HASS requires Safety of Screen

HASS uses the highest possible stress conditions to perform fatigue damage accumulation or lifetime degradation. Since these stress conditions exceed product specification levels, there is substantial risk of damage to production units if a) HALT is not performed, and b) if Safety of Screen is not performed. Safety of Screen is therefore absolutely essential, and is used to prove empirically that the specific HASS profile is safe.

All screens (e.g. ‘run-in’ and ‘burn-in’) remove life from products. However, the goal of Safety of Screen is to prove that a negligible portion of life would be removed in HASS. The relevant question is therefore “How much life is left after HASS?” and not “How much life is removed in HASS?” [6].

Safety of Screen is based on repeating the derived HASS profile (e.g. 20 times). How is it possible to precipitate and detect a defect (or flaw) without causing damage to good products? Process flaws cause much higher than normal stress at the flaw position than at a position without a flaw. Using Miner’s criterion, it can be shown that if the stress were 2 times higher at the flaw position, fatigue damage would accumulate about 1,000 times faster at this position. This means that HASS can fatigue and break a flawed area and still leave 99.9% of the life in the non-flawed areas [6].

3.7 HALT & HASS require training of personnel

HALT & HASS require adequate training of personnel to fully understand the processes. Design and production engineers should especially be comprehensively trained. Training should not only focus on ‘hard’ technical issues, but also on ‘soft’ human aspects. A designer should understand that HALT may identify design weaknesses, and that these weaknesses should not be seen as ‘personal failure’.

Adequate HALT & HASS training of personnel is necessary irrespective of whether HALT is performed in-house or at an independent laboratory. HALT should never be subcontracted to an independent laboratory without active participation of knowledgeable design engineers.

Similarly, HASS should be performed by production personnel, whether in-house or at an independent laboratory. Some organizations incorrectly assume that HALT & HASS can be performed by personnel from the quality department. Quality assurance personnel can certainly contribute to the process, but should not have the primary responsibility.

Training is also required for personnel responsible for operation and maintenance of the HALT facility.

3.8 HALT & HASS require special environmental test chambers

HALT & HASS require the use of special environmental test chambers to subject development or production units to stresses exceeding product specification levels. Typical HALT & HASS chambers provide simultaneous multi-axes broadband vibration and rapid thermal cycling. Vibration has six degrees of freedom (i.e. three linear and three rotational axes) up to 100Grms. Thermal cycling consists of cycles between -100°C and +200°C with ramp rates of larger than 60°C/minute.

A study performed at a HALT laboratory recorded test results for 47 products (from 33 companies representing 19 industries) [9]. Classical HALT was used, and failures observed are shown in Figure 10. The tests were performed sequentially, and the percentage per test shown refers to additional failure modes identified. Other research on HALT results tends to support these findings.

The results suggest that many failure modes may remain undetected unless special HALT test equipment is used. Conventional environmental test equipment may be used to perform HALT & HASS, but it is therefore not recommended.

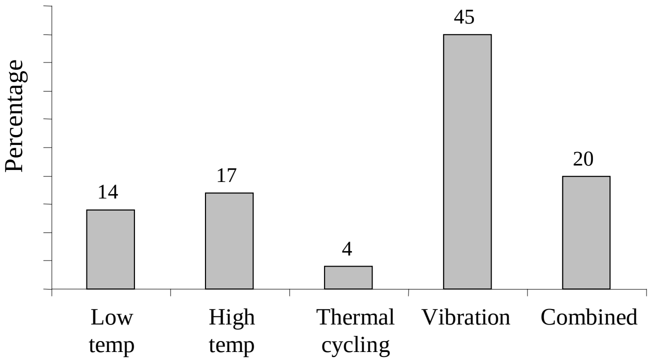

Figure 10 - Classical HALT failure modes observed

3.9 HALT & HASS require corrective action

Corrective action is the implementation of a design or process change to eliminate the observed failure mode. The change should only be implemented if the root cause of the failure mode is well understood, which may require substantial in-depth analysis and test.

It should be emphasized that HALT & HASS cannot improve product reliability; only people can implement the necessary design and process changes. HALT & HASS can only identify design and production weaknesses. If these opportunities are not taken, reliability will not be improved.

Since HALT & HASS may identify failure modes using ‘unrepresentative’ stress conditions, it is easy for engineers to ignore important product improvement opportunities. Corrective actions should also be verified, which may include a re-HALT to verify that a problem has indeed been solved (and that new problems were not introduced).

3.10 HALT & HASS require top management support

Implementation of HALT & HASS requires a paradigm shift from everybody in an organization, including top management. HALT & HASS typically require substantial investment in terms of the following:

- HALT chamber(s)
- HASS chamber(s)
- compressed air facility
- liquid nitrogen facility
- additional development models for HALT
- additional production units for HASS
- operating expenses (e.g. liquid nitrogen)
- personnel to manage HALT facility
- personnel to manage HALT & HASS processes
- training of technical personnel
- implementation of corrective action

Although there is no difference between a HALT chamber and a HASS chamber, many organizations purchase one chamber for HALT, and one or more for HASS. Organizations attempting to perform both HALT and HASS using the same chamber quickly learn that the chamber is seldom available for HALT (depending on production volumes). The size of a HALT chamber is determined by the size of the test units, while production volumes typically determine HASS chamber size.

Management should take note of the requirement for dedicated personnel (for both HALT & HASS facility and management of processes). When introducing HALT & HASS to an organization, there is significant risk of failure if this requirement is ignored. Both HALT & HASS are important engineering processes, which require dedicated 'process owners'. Also, due to the costs involved in establishing a HALT & HASS facility, it is imperative that a specific person is made responsible for management (i.e. operation and maintenance) of the HALT & HASS facility.

Figure 11 shows results from a study performed to determine the relationship between annual return rates (i.e. field failures) and product operating margin [10]. The results clearly show the financial benefit of a higher operating margin (i.e. more robustness), since the annual return rate has a direct and negative impact on profit.

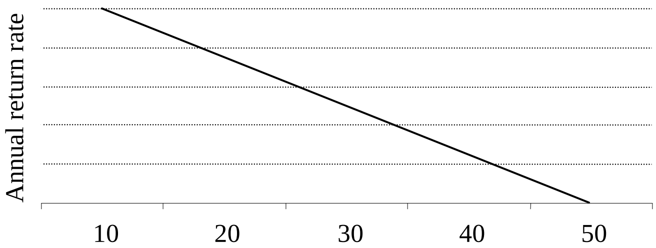

Figure 11 - Annual return rate vs operating margin (℃)

Whether or not an organization invests in HALT & HASS, often depends on whether top management views it as short-term expense or as long-term investment.

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Albertyn Barnard received the degrees M Eng (Electronics) and M Eng (Engineering Management) from the University of Pretoria, South Africa. He has provided consulting services in reliability engineering to the defense, nuclear, aerospace and commercial industries since 1982. He provides training in reliability engineering to industry and at post-graduate level at the University of Pretoria. He has presented numerous technical papers, and won the Best Paper Award at the 2004 INCOSE SA conference (South Africa), as well as the Gold Award at the 2009 International Applied Reliability Symposium, Europe (Spain). He served as President of INCOSE SA (South African chapter of the International Council on Systems Engineering) in 2008. Albertyn is a member of IEEE and INCOSE. Lambda Consulting specializes in reliability engineering activities applicable to product development, and established the first commercial HALT laboratory in South Africa in 2008.