EVOLUTION OF HALT AND HASS ON AEROSPACE PROGRAMS

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ABSTRACT

Recent high profile failures of avionics Lithium Ion battery systems and concentration on reduced design cycles seems to imply that there are still failure rates in aerospace programs. This paper is based on another written by Dr. Gregg Hobbs (the inventor of HALT and HASS) in 2002 pointing out field failure rates of aerospace programs that at the time were running in the 20-50% range on the systems level. The late Dr. Hobbs predicted that as avionics systems became more complicated and the number of sub-systems on board increased, that the opportunity for defects would also increase. This, of course, causes a worsening of the general failure rate at a much higher cost to companies.

We have seen a dramatic increase in automotive and avionic electronics reliability over the past 15 to 20 years as more automotive and aerospace sub-systems are deploying accelerated life testing using HALT. For the automotive industry as these methods are mandated to suppliers and more suppliers start incorporating HASS testing, we see a general improvement in the reliability of automobiles. They are finding process weaknesses before they reach the customer. On many products, field failure rates have approached, or actually reached, zero.

With satellite and space technology we have only one chance to find design and process weaknesses. The above mentioned techniques in the author's opinion are absolutely necessary to learn how much design margin exists in each sub-system prior to deployment of the spacecraft.

BRIEF HISTORY OF HALT

HALT (Highly Accelerated Life Tests) has been in use since 1969 by Dr. Hobbs, the inventor of the methods. In that year, the Casagranian telescope for the Multi-Spectral Scanner (MSS), which flew on the Earth Resources Technology Satellite, was subjected to HALT, first in the finite element model and then in the laboratory. The finite element model was completed and run several times including design modifications to eliminate weak links before any hardware was built, so no design weaknesses were found on the prototype in severe overstress testing. The resulting design was very robust. This turned

out to be very beneficial as the end use environment changed significantly from that used in the design analyses. The original design was adequate even though the field environment increased significantly. The electronics on that same satellite sub-system were also exposed to overstress conditions analytically. No failures occurred during qualification testing or in flight. The MSS is shown in Figure 1 below and the telescope is shown in Figure 2.

Figure 1 - The Multi-Spectral Scanner used on the Earth Resources Technology Satellite, 1970, by permission of Santa Barbara Research Center.

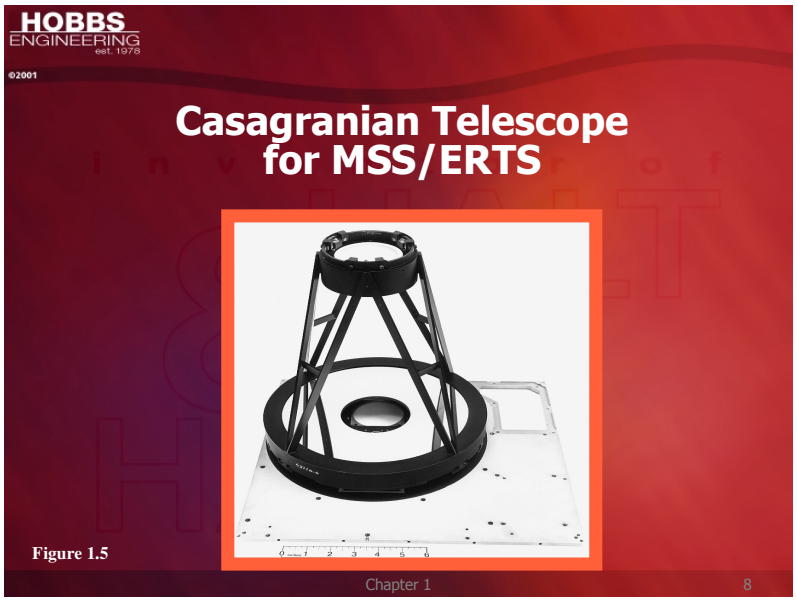

Figure 2 - The Casagranian Telescope of the Multi-Spectral Scanner, by permission of Santa Barbara Research Center.

HASS (Highly Accelerated Stress Screens) was first used in 1979 on the Sidewinder Target Detector (proximity fuse), the AIM 9-J. In that effort, a true six-axis simultaneous shaker and a combined high rate chamber were used in the accelerated stress screens. Field results reflected the fact that fewer defects were passed on to the customer than had been normal in that day. As a result of HALT and HASS, and the improvements on the product due to them, Santa Barbara Research Center received the entire contract after another vendor could not even come close to the reliability of the SBRC product. The inner housing of the Proximity Fuse is shown in Figure 3 which is from Chapter 6 of reference 1, again by permission of Santa Barbara Research Center.

Figure 3 - The Target Detector for the Aim 9J Sidewinder Missile.

Since these early applications of the then-developing methods, there have been vast improvements in the techniques and the equipment used to perform them.

Current and more advanced technology is at a much higher level of integration including embedded control firmware. Current HALT techniques enable full mapping of electronic and electro-mechanical environmental dynamics. That is, with proper instrumentation of the module under test while it is in the chamber, we can see firmware error conditions. The ranges and limits are reached at points where we would expect them to occur. We can validate that the design is working as intended and that there is sufficient margin above the design specified environment that is expected. The real value of HALT is when we discover a failure mode that has not been predicted by modeling techniques alone.

DEFINITION OF HALT

HALT consists of several steps during the design phase aimed at finding opportunities for improvement in the design and these are:

- Apply any "stresses" that could cause weaknesses in the product to be exposed. This means any stresses, not just those that occur in the field. It is quite normal in HALT and HASS to find a defect using a different stress than the one that would cause the failure to occur in the field. For example, the same defect that occurs due to long exposure to IR radiation may be precipitated by 6-axis vibration in the HALT chamber in a matter of a few minutes or hours.
- Detect the defect. This requires a high coverage test and the correct combination of stresses to accomplish.
- Failure analysis. Determine why the product was weak.
- Corrective action. Determine how to correct the weakness.
- Verification of corrective action. Put in the fix and retest to determine that the failure mode is no longer present.
- Enter the fault and fix into a database. Set up a design guidelines manual for the particular product and end use environment. This is the lessons learned file that is so important in not making the same mistake again. If we do not do this, then newcomers will typically make the same mistakes at some later date.

Note that, if any one step is omitted or not accomplished correctly, the following step(s) cannot be accomplished.

DEFINITION OF HASS

HASS consists of several steps during production aimed at finding opportunities for improvement and these are:

- Precipitation. This means to change a latent defect into a patent defect using precipitation screens, which may use stresses above the normal operating environments as well as stresses that do not occur in the normal operating environments.
- Detect the defect with high coverage testing and detection screens.
- Failure analysis.
- Corrective action.
- Verification of corrective action.
- Enter the fault and the fix into a database.
- Re-HALT as appropriate to determine if the obtained margins are retained.

A FEW RESULTS FROM THE USES OF HALT AND HASS

Taken from the author's more recent experience, the results of HALT are dramatic.

A precision robotic device with many electronic and electro-mechanical sub-systems was designed to a 10 year service life. The electro-mechanical sub-systems were tested using conventional cycle testing methods at ambient room temperature. After experiencing many issues with PCBA assembly integration incompatibilities, during the next design iteration HALT testing was employed. Some of the root cause issues that were found very rapidly in HALT were:

- On-board voltage regulators not operating within range during voltage margins testing at low temperature. A simple resistor value change enabled mitigation of the failure mode. No re-design costs other than a part specification BOM change.
- A firmware out of range fault created an error condition as a false loss of positional feedback. Two changes were made, one to the firmware range values and one to incorporate precision ceramic capacitors that were less sensitive to temperature variation. Very low re-design costs but priceless reliability gains.

An electro-optical assembly that was produced in high volumes had a BGA ASIC and a BGA flash memory. During HALT testing it was found that during rapid excursion to cold and with about 10 GRMS vibration applied, both the ASIC and the flash memory BGA solder joints would crack. The failure was very repeatable at -20C and 10 GRMS in the HALT chamber. After improving the surface flatness specifications on the PCB and increasing the size of the pads and solder paste, the board was able to sustain -45C and 50 GRMS, a substantial margin improvement over the specified environment of +5 to 45C at 5 GRMS.

If we have done such a great job of insuring extremely large design margins why do we ever need to do HASS? Because no design margin is large enough to compensate for random events in an assembly process, and only extremely well controlled supplier processes will produce uniform parts throughout the entire product lifecycle. From years of experience, the types of defects that are exposed during HASS are <u>completely</u> unpredictable. Even the most disciplined and well controlled supply chain cannot prevent random defective parts, or in the case of HASS detection, weakened parts from entering the manufacturing process.

So here is a short list, by no means all inclusive, of the types of variances found in HASS (in this author's experience) that have little, if any, connection to the design process. Some of the following defects could have been prevented through applying DFM Poke Yoke techniques.

- Mechanical part machining variance.

- Hidden supplier cost reductions that affected design strength but did not affect the manufacturers published specifications for the part.
- Hidden supplier process changes that the supplier is unaware of such as contamination of chemicals during PC fab.
- Aging of solder paste prior to reflow during line shut down for an extended period of time.
- Incorrect loading of firmware – Shows up due to diagnostic software used in HASS, not the HASS test itself, some defects are revealed at the initial ambient temperature step with no stress applied at all.
- Sub-assembly PC board change – Similar to the encoder example above that was not revealed by the supplier via design change notification.
- Defective power regulators – Found during HASS at a supplier of power supplies. Their rapid notification of this to our company prevented an interruption of our supply chain to OEM customers by allowing us to take contingency actions.
- Delamination of a 16 layer PCB assembly.
- Cracking of motor magnets due to a formulation change that was two suppliers removed.
- Incorrectly installed power filter capacitors – Polarity reversed and not detected during previous functional testing. Capacitors exploded during over-voltage at hot temp.
- Insufficient adhesive application on optics inside of optical housing. Showed up with tickle vibe during initial cold temp excursion.
- Numerous examples of BGA solder defects.
- Flash memory not loading correctly at cold temp – Supplier process change caused this and they were unaware of any ill effects of the change through their automated screening test process.

SOME GENERAL COMMENTS

One can readily see that the last step (the data base) in HALT and in HASS is a crucial one, as without it, the same mistake will occur over and over again. This step, that is, the process of trying to remember what did and did not work, is crucial in establishing good quality and reliability and then in maintaining it. Many aerospace companies are incorporating lean engineering disciplines which, at the core, require rapid learning cycles to occur and finally the learning is applied to value streams in product development.

There is no valid reason why the methods should not be applied to aerospace designs. Taking the LCD display on a passenger seat back as an example we have an electronic module with fine surface mount parts that is constantly receiving various forms of shock waves from seat repositioning, takeoffs and landings, trays, getting knocked by vacuum cleaners, luggage and all forms of passenger carry-on items. The accumulated damage takes its toll and over time weaknesses precipitate as failures. The same weaknesses can be discovered and remedial action can be taken in a matter of hours during HALT testing to achieve product ruggedization.

Let's examine a few reasons put forward for not using HALT and HASS and make comments on each one. The misconception is in bold for clarity.

Satellites are different. Sure they are. They cost a whole lot more and are difficult or impossible to repair once in orbit and it is, therefore, even more important that they be reliable. However, an electronic box is an electronic box as far as HALT/HASS are concerned. The weaknesses found are the same ones that cause field failures. Thousands of programs have proven this. The approach is the same regardless of the type of hardware and its intended use.

Costs too much. Actually, many case studies that are openly published show cost reductions even for limited production programs. Without robust margins, no product will be reliable or low cost (if the cost of operation is included). Many near operating margin failures present as returns that are "no trouble found". These warranty returns more than cover the cost of the chamber and testing. Once the product is ruggedized it is ready for lifecycle operation vastly supporting the wasted cost of product maturity over time as field failures and retrofits and ongoing revisions.

We don't build very many units. Only one HALT unit is required as stress level is substituted for sample size. If one unit cannot be stressed to find and improve the operational and destruct limits and for screen development, then the benefits are not possible. Would you rather build two space probes, one a HALT unit and one a flight unit and have a successful mission, or would you rather build just one flight unit and have it fail to perform? Hmmm! Which approach is cheaper?

Capital costs are too high. The author has seen, not once but many times, the HALT equipment pay for itself in minutes by saving companies from bankruptcy or severe loss of market share.

We'll have to break the hardware. Right! This is the point of the whole experiment. We plan to find all of the weak links. So just fix the weak link and continue on until there are no more weak links remaining. One sacrificed unit in HALT will lead to much higher reliability of production units.

We are not making cars here. Weaknesses are weaknesses in whatever product you care to mention and this is what causes field failures. The techniques work on most products if one applies them correctly and then fixes what is found to be weak. The most commonly made mistake is not to fix what is found to be weak. The whole point is to find and fix the weak points in the designs or processes.

We already thermal cycle and vibrate. Do a rational cost/benefit analysis. The results are poor and the costs are high. Accelerated test conditions will achieve exponential time and, therefore, cost compression. In the authors experience many pieces of test equipment can be eliminated or made obsolete by employing HALT testing methods. That means fewer test samples are necessary. In addition, several environmental tests

such as altitude, salt spray and temperature/humidity can be performed prior to HALT and still find additional weaknesses during the HALT test.

But, we'd have to build extra hardware. In the final analysis, fewer units will have to be built (unless you intend to make only one) using the HALT/HASS approach as most will work as intended and fewer spares will be needed.

We don't have time for HALT. Actually, HALT speeds the design phase, therefore reducing cost, if done correctly. HASS will find process problems before field failures occur and before a large number of flawed units are built and shipped. Therefore, HASS saves time and money as well, again, if and only if done correctly.

CONCLUSION

The technology for successfully finding weak links in products has existed for many years now. Thousands of companies are successfully using HALT and HASS on a myriad of products. HALT testing is well accepted in the aerospace, defense and consumer industries. Any opportunity to try the methods will result in discovery of interacting variables in the design that are still very difficult if not impossible to model using even the best FMEA or computer aided finite element modeling methods. HALT testing facilities are available to try the methods to convince you that it should be added to your regimen of environmental testing and validation.

BIBLIOGRAPHY

1.Hobbs, Gregg K., "*Accelerated Reliability Engineering, HALT and HASS*", Hobbs Engineering Corporation, 2005.

BIOGRAPHY

Aldo Fucinari has 35 years experience in design validation testing, electrical engineering and environmental testing and holds a BSEE degree in Electrical Engineering. He has worked in various roles of quality and design engineering including computer peripheral storage , automotive electronics and engine test systems, audio products and systems engineering. Aldo has held quality engineering positions at Kulicke & Soffa, Emulex Design and Manufacturing and Seagate and was responsible for customer quality to IBM, Dell, HP, Cisco, EMC, Network Appliance, Ford, General Motors and is currently a senior consultant to bio-medical and aerospace firms through Hobbs Engineering. Aldo learned HALT and HASS methodology from Dr. Gregg Hobbs who mentored him since 2005.

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