Why Use Research Quality Instruments?

When we conduct thermal measurements, or when we plan for a new lab, we naturally ponder the quality and the cost of our instruments. Are we also questioning their accuracy? How do we know the instrument we are buying is accurate? What is the impact of this accuracy on our work and on the products we want to introduce to the marketplace? Most, if not all, of these questions can be answered by looking at the impact of errors in temperature measurement or calculations on reliability analyses.

The life expectancy of most products is estimated at some point prior to their introduction. Reliability analyses are an integral part of the design cycle of a product. In all reliability calculations, temperature is the key driver. The predicted life span from these calculations is often the deciding factor for introducing the product or investing more resources in redesign.

The questions that linger are: to what level of accuracy can we determine the temperature magnitude, and what is the impact of temperature uncertainty on the predicted reliability (i.e., the expected life of the product)?

When a system is operating, it incessantly experiences temperature and power-cycling. Such fluctuations, resulting from system design and operation, or from complex thermal transport in electronic systems, create large bandwidths in temperature response. Whether it happens in the course of an analysis or a compliance/stress testing, we often overlook the accuracy by which temperature is measured or calculated. Yet to truly obtain an adequate measure of a system's reliability in the field, such temperature data is essential.

To demonstrate the impact of temperature on reliability, consider the two models commonly used in practice. The Arrhenius model [1], often referred to as "Erroneous", is perhaps the most broadly used model in the field. Equation 1 shows the reaction rate (failure rate) k and the acceleration factor A_T. K_B is the Boltzmann constant (8.617×10^{-5} eV/K) and E_a is the activation energy. All temperatures are in Kelvin. Activation energy depends on the failure mechanism and the materials (for example, 0.3 - 0.5 for oxide defects, and 1.0 for contamination).

$$k = k_o e^{-\frac{E_a}{k_B T}} \qquad A_T = e^{\frac{E_a}{k_B}\left[\frac{1}{T_1} - \frac{1}{T_2}\right]}$$

Equation 1.

The second model, Eyring, often referred to as "More Erroneous," is shown by Equation 2.

$$k = k_o^{'} T^{n} e^{-\frac{E_a}{k_B T}}$$

Equation 2.

The accuracy of these models is highly debated in the field but, in the absence of better models, they are used regularly. Both models certainly serve the purpose of our discussion here (i.e., to show the role of inaccurate temperature data and its impact in reliability calculations). Both models exhibit exponential dependency on temperature. Therefore, any error in temperature estimation, either analytical or experimental, may be amplified exponentially while estimating reliability performance.

The data shows that the uncertainty band is between 7 to 51%. These numbers by themselves are alarming, yet they are commonly encountered in the field. In either case, Stand-Alone or Device-In-System, being able to accurately determine the temperature or air velocity in a highly three-dimensional thermal transport environment is not a task to be treated casually.

To measure the impact of such uncertainty on the reliability prediction, it's best to calculate its impact on the Acceleration factor A_T.

Let us consider the case when:

T_1 = 40°C
T_2 = 150°C
E_a = 0.4 eV
k_B = 8.6x10^{-5} eV/K

This results in A_T = 48. Now, let us impose a 10% and 35% uncertainty on the temperature measurement of T_2. Table 1 shows the result of this error on the acceleration factor.

Table 1.
Effect of uncertainty in temperature measurement on Acceration Factor (A_T).

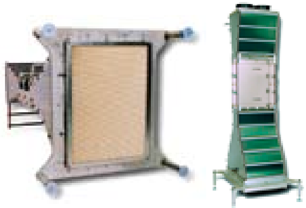
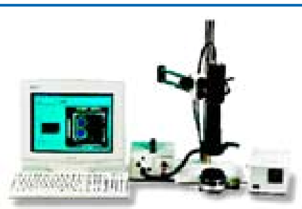
Uncertainty	Temperature (°C)	Acceleration Factor (A_T)	% Error
0%	150°	48.0	0%
10%	165°	69.4	43.7%
35%	202°	158.6	230.0%

Table 1 clearly demonstrates how a small degree of uncertainty in temperature measurement can negatively impact the Acceleration Factor and, thus, the reliability predictions where A_T is often used. The first row shows the correct temperature. The second row shows the result of a 10% error in temperature measurement (i.e., 165°C instead of 150°C). The last row shows the impact of a 35% error (i.e., 202°C vs. the 158.6°C that the device is actually experiencing). The end result of this error in measurement is a 230% error in the Acceleration Factor.

One may think such an error is rare, but the contrary is true! In a simple device-case-temperature measurement, the temperature gradient could be in excess of 20°C from the die to the edge of the device. Or the air temperature variation in a channel formed by two PCBs could exceed 30°C. Of course, there are variations due to geometry, material and power dissipation that are observed in any electronics system. If we add to these the effects of improperly designed instruments, the combination of physical variation and the instrument error could certainly be detrimental to a product's launch.

THERMAL ANALYSIS

Longevity and lifecycle in the market are keys for a product's success. Therefore, to determine system performance, a reliability analysis must be performed, Since time is of the essence, and first-to-market is advantageous, the quickest reliability prediction models (analysis in general) will continue to be popular. To make such models, the use of Equations 1 and 2, or others more meaningful, must include accurate component and fluid temperature data. Measurement is heavily relied upon for temperature and air velocity determination. It is imperative to employ instruments designed for use in electronics systems with the highest level of accuracy and repeatability. High-grade instruments with quality output will enhance the reliability of the product you are working on. Table 2 features such instruments offered by ATS.

PRODUCT	FUNCTION	ACCURACY	APPLICATION DOMAIN
ATVS-2020 	• Measures air velocity and temperature with a single sensor for full range • Measures surface temperature	• Temp range -30 to 150°C ±1°C • Vel. Range 51 m/s(0-10,000 Ft/min) ± 2% • All components are 0.1%	**ATVS-2020** is designed to measure air velocity & temperature in electronics systems. One sensor measures the full range of flow. There is no need to change sensors for different flows.
ATVS-NxT 	• Measures air velocity and temperature with a single sensor for full range • Measures surface temperature • Fully portable	• Temp range -30 to 150°C ±1°C • Vel. Range 0-10,000 Ft/min (51 m/s) ± 2% • All components are 0.1%	**ATVS-NxT** is designed to measure air velocity & temperature in electronics system. One sensor measures the full range of flow. There is no need to change sensors for different flows.
WTC-100 	• Precision fan controller manages air flow through a wind tunnel or fan tray • PC driven • All data acquisition and control is automated	• Controls air velocity to ± 2%. • Use ATS patented ISD Sensor technology • Measures air temperature to ±1°C	**WTC-100** is used in conjunction with a wind tunnel, single fan or fan tray. Suitable for any air flow testing where control or testing automation is required.
CWT-106 	• Research quality wind tunnel designed for component, heat sink, single- and multi-PCB thermal simulation • Can be placed horizontally and vertically • Highly customizable	• Air flow range from 0-2000 ft/min, (10 m/s), depending on fan tray. • Air flow variation at the entrance of the test section is ± 1.5% • Plexiglas™ sidewalls allow complete visual access to the entire wind tunnel	**CWT-106** is designed for all classes of testing that require known flow rate. In conjunction with the WTC-100, it provides a unique and automated thermal testing facility for single device or heat sink, PCBs, and a stack of PCBs.
thermVIEW™ 	• The Liquid Crystal Thermography (LCT) system is designed to measure the temperature of part, die, and PCBs • A complete turnkey system	• Temp range -10 to 160°C. • Temperature accuracy is ±0.1°C • Spatial resolution with non-encapsulated liquid crystal is 1 micron • Capable of temp. measurement through glass or Plexiglas™	**ThermVIEW™** is designed for applications where precision measurement is required. Whether a transistor on a die or the entire PCB. Highly accurate and repeatable.
FCM-100 	• FCM-100 is a Fan Characterization Module designed to produce the fan curve for either a single fan or multiple fans or an entire fan tray	• Measures fan mass-flow rate (or volumetric flow rate) with ± 2% accuracy using ATVS-2020 flow measurement technology • Accurately measures pressure drop by micro-manometer	**FCM-100** is designed to provide bench-top fan/tray characterization capabilities to engineers. The system can be retrofitted to also measure pressure drop for a single PCB or full card rack.

SUMMARY

Small errors in temperature and air flow measurements can have a significant effect on reliability predictions. The origin of these errors lies in the measurement process or the use of inaccurate instruments. The former depends on the knowledge-base of the experimenter. That is why “a good experimentalist is even a better analyst.” You must know where to measure and the variations that exist in the field of measurement. Electronics system environments are notorious for such variations. It is repeatedly seen that, in one square centimeter of air flow passage between two PCBs, you can have temperature variations in excess of 30°C. Therefore, measurement practices and instrument selection must address these changes and not introduce further errors because of inferior design. Besides its design, an instrument’s construction and calibration should not introduce more errors. Accurate and high-quality instruments are not only essential for any engineering practice -- their absence will adversely impact reliability predictions of a product at hand. No company wants to have its products returned, especially because of thermally induced failures.

Nomenclature:

A_T =	Temp. Acceleration factor
E_a =	Activation energy
k =	Reaction rate
k'_o & k_o =	Pre-exponential factor
k_B =	Boltzmann constant
n =	Relates to reaction dynamics (0.7)
T =	Temperature (K)

References:

1. Klinger, D., Nakada, Y., and Menendez, M., AT&T Reliability Manual, Van Nostrand Reinhold, 1990.

2. Azar, K., The Effect of Uncertainty Analysis on Temperature Prediction, Therminic Conference, 2002.