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# RELIABILITY MODELING AND FAILURE ANALYSIS OF COMPLEX ELECTRONIC ASSEMBLIES UNDER DYNAMIC STRESS

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## ABSTRACT

*This report compares the reliability modelling and failure of electronic assemblies that are subject to dynamic loads based on secondary research. The most significant results are major failures, prediction models, and improvement strategies. Findings highlight the importance of multi-stress testing and multi-disciplinary modeling techniques in order to increase long-term durability and reliability behavior.*

***Keywords:*** *Reliability, Dynamic Stress, Failure Analysis*

## INTRODUCTION

The growth of integration of components in the present-day systems, like aerospace, automotive, telecommunication and medical equipment, has led to reliability of electronic assemblies as a key area of research. These systems experience dynamic stresses such as mechanical vibration, thermal cycling, and humidity as well as changes in electrical load and this increases the rate of degradation and causes operational failures. To make sure that the performance will be guaranteed in the long-term, a systematic approach to reliability modeling and failure analysis should be provided. This paper looks at the impact of dynamic stress conditions on failure behaviour and methods of modeling to achieve the prediction of life expectancy and maximize dependability.

## LITERATURE REVIEW

### Introduction

Literature on reliability modelling and failure analysis of electronic assemblies at dynamic loads shows that there has been a massive growth within the past decades. Researchers have examined the acceleration of degradation by environmental loads like temperature, vibration and electrical fluctuations on components. It is noted in research that the modelling techniques are crucial to forecast the reliability and comprehend the behaviour of complex circuits in adverse operating environments. Other studies also emphasize the different failure mechanisms and life prediction models that assist in engineering choices. Nevertheless, the results are heterogeneous and scattered and it is necessary to systematize the study on an overall basis. The paper is a review of existing literature to provide a procedural insight into the issue of reliability in electronic assemblies.

### Reliability of Electronic Assemblies Under Dynamic Stress

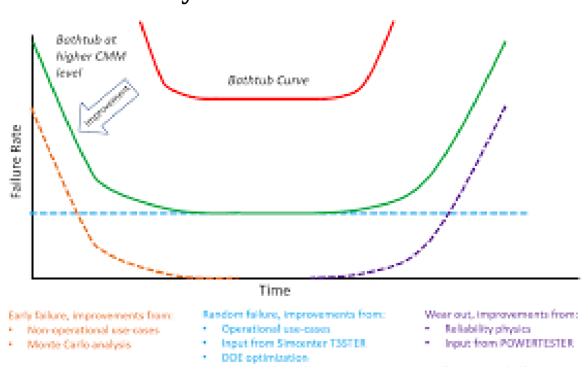


**Figure 1:** Achieving Physical Reliability Of Electronics

(***Source:*** https://i0.wp.com/semiengineering.com)

Studies on the electronic assemblies point out that the external stress factors that greatly affect reliability include heat, vibration, humidity, cycling load and electrical overstress. It has been found out that aerospace, medical and automotive systems usually experience failures because of accumulated fatigue and material degradation when subjected to repeated dynamic loads. Stress life interactions have been studied to determine the degradation behavior of solder joint and interconnects during a period (Yi et al., 2018). The results have shown that concomitant stresses cause faster failure than univariate stress exposure, which implies that reliability analysis should be conducted by multi-environment scenarios. Failure thresholds and mean time to failure estimation are also frequently discussed in many papers offering information on the effects of stress intensity on operational lifespan.

**The Failure Mechanisms of a Complex Assembly**

According to research on failure modes, the most common way of assembling failure is through solder joint cracking, delamination, electromigration, corrosion and thermal fatigue. Dense circuit packaging makes it more vulnerable to mechanical and thermal dissimilarity which causes crack propagation when vibrating and subjected to temperature variations. One research reveals that expansion and contraction cycles repeatedly cause the weakening of interconnect bonds and rise in levels of resistance to a point when functional breakdown will take place. Microscopic examination and cross-sectional analysis investigations prove that microstructural changes are reliable early signs of failure (Cogliati et al., 2016). There are papers that emphasize the effects of moisture and contamination to hasten corrosion and papers that mention that electrical over stress leads to burning of a material.

**Reliability Modeling Techniques**


**Figure 2:** Reliability Methods

(***Source:*** https://s3-us-west-1.amazonaws.com)

Studies indicate that statistical, analytical and simulation methods often form the basis of the reliability modelling. Weibull distribution is often applied to model the probability of a device failure and its lifespan, whereas the Arrhenius model is applicable in modeling a degradation caused by temperature. Models that are modeled using physics-of-failure are used to simulate stress concentration regions and crack growth. Using the finite element analysis, thermal distribution of parts and vibration forces among parts are mapped. The latest literature presents machine learning models of predicting failures based on large reliability datasets (Mittal and Vetter, 2015). Accelerated life testing has been also reported in literature as a useful method to create failure data in a short time. In general, the reviewed journals confirm that a statistical prediction together with physical modelling advances the accuracy of predicting performance in dynamic stress.

**Strategies of Improvement Reliability**

Numerous publications propose methods to achieve reliability by optimisation of the material, enhanced thermal conductivity and sturdier design. The reinforcement of solder alloys, underfill materials and compliant interconnects are noted to be effective solutions to mitigate fatigue. Better temperature stability is ensured by improved heat sinking, thermal vias and airflow design. Some of the stress-relieving measures suggested by researchers include vibration damping and controlled load distribution on PCBs. Real-time condition monitoring with sensors is also a proposal in papers in order to identify the early degradation. Enhanced encapsulation and protective coating is said to improve corrosion resistance in an adverse setting (Levin et al., 2019). The considered work as a whole justifies the necessity to incorporate reliability-oriented design since the first stage of development to provide a longer working life under multi-stress conditions.

**Literature Gap**

Although there is abundant research in the field of reliability modelling, the failures of electronic assemblies when subjected to dynamic stress still have several gaps to be filled in the learning. Much of the literature that exists investigates the concept of reliability when subjected to single stresses like thermal stress or only vibration but not combined stresses as they occur in reality. This makes the results less transferable to real world settings. Most research is based under controlled laboratory conditions which are not representative of random field variations and uncertainty factors that affect reliability when operating over a long time period. Little connection between modelling and real time failure monitoring is also observed in the literature, which leads to poor connection between predictions and actual failures behaviour (Jiao et al., 2019). Moreover, interactions between microstructural degradation and system-level performance response are rarely studied thus prediction is not as accurate in highly dense contemporary circuits. Modelling techniques have been well documented but comparative analysis amongst models has not been very well done particularly in regards to accuracy, sensitivity of stresses and scalability.

**Conceptual Framework**

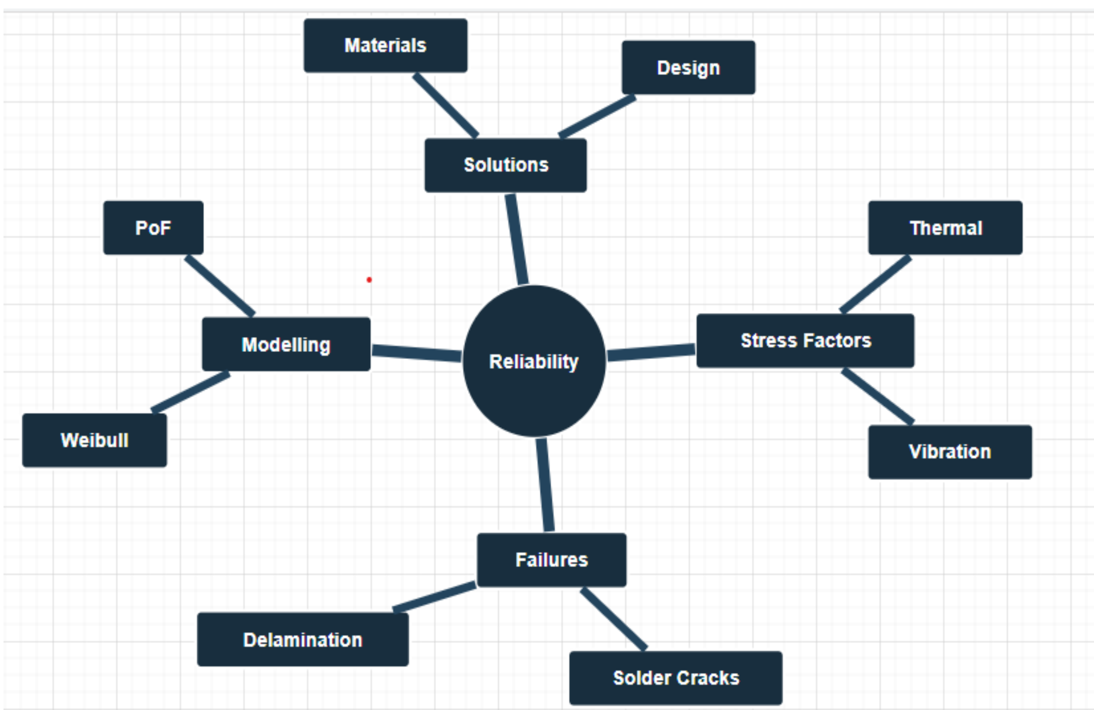


**Figure 3:** Conceptual framework

(***Source:*** Self-created in draw.io)

## CONCLUSION

The literature reviewed confirms that dynamic stress has a powerful influence on the reliability, which leads to an active process of developing cracks in the solders, interconnections, and packaging structures. Several computational models like the Weibull analysis, Arrhenius acceleration, finite-elements and physics-of-failure models are helpful models to make predictions and evaluations. The failures that have been identified in past studies indicate general trends that may be used to inform the improvement measures in the design, material choice, and stress functionality.

## METHODOLOGY

### Research Approach

The methodology of the research will entail a systematic search of the published literature to learn the way that reliability has been modeled in complex assemblies. The implementation is initiated by the selection of the papers describing the thermal cycling, mechanical vibration, and multi-stress failures (Xing et al., 2019). Results are then tabulated to assess the projections of life expectancy by researchers, the degradation course and the study of component failures.

### Research Design

The design is structured after stages. To begin with, shortlisting of literature concerning dynamic stress reliability is done. The further step involves the extraction of the statistics like model type, stress variables, component type and the observed failure mechanisms into structured notes. These details are subsequently matched up later to compare effectiveness of prediction models in various studies.

### Research Method

The process is carried out through the review of articles that reported stress-induced failures through the use of models such as Weibull analysis, Arrhenius acceleration factors as well as physics-of-failure-based simulations (Ma et al., 2016). Each study is evaluated to determine the way degradation was quantified, how failure limits were determined, and how reliability results were understood. The procedure aids in improving the knowledge on life prediction methods in actual working conditions.

### Data Collection

The data is only gathered in its secondary form such as journal articles, conference papers, reliability handbooks and technical reports that are associated with electronic assembly failures when subjected to dynamic loads. The parameters of stress, failure rate, model outputs, test conditions, and parameters to indicate degradation are specifics which are elicited and documented in a systematic manner (Hanif et al., 2018). The acquired information is subsequently compared and sorted into groups in order to examine the common patterns of failure and methodologies of modelling reliability predictions.

### Research Ethics

Ethical issues are upheld through a fair use of published information, proper interpretation of findings and display of results. The research does not distort or overstate the results of research that was reported and all information that was referred to other works is credited. The utilization of data is not concerned with commercial use in any way: data is analyzed academically, respecting the intellectual property and not being subjective when synthesizing or comparing.

## RESULTS

### Mechanisms of Failure Investigated

The literature that was reviewed shows that the most common failure mechanisms are thermal fatigue, cracking of solder-joints, electromigration, mechanical vibration damage and delamination of materials. Assemblies of electronics that experienced temperature cycling suffered a gradual micro-cracking as a result of a thermal incompatibility between parts and substrate. Investigations with the state of vibration revealed breaking bond, fracture lead and PCB trace damage particularly when resonance frequency equated component structure (Yang et al., 2018). Corrosion related to humidity was a common phenomenon in assemblies that lacked protective coating which resulted in resistance and intermittent failure.

### Outcomes of the modelling and prediction.

Predicted reliability studies indicate that Weibull distribution to determine life prediction was the most widespread method of prediction followed by Arrhenius-based acceleration to determine the rate of degradation due to temperature. Physics-of-failure modelling provided more information about crack propagation and the areas of stress concentration, whereas the finite element simulations were used to visualise the thermal gradients and the response to vibrations at PCB layers. The reports that combined simulation outcome with experimental failure data with high accuracy indicated that the mean time to failure outcomes were accurately predicted. Machine learning models had potential in predictive maintenance, particularly when they were trained using historical reliability data.

### Stress Effect on Component Life.

It is a consistent observation in the literature that mixed stress habitats reduce component life significantly. As an illustration, solder joints are damaged more rapidly when subjected to both heat and vibration than when subjected to thermal cycling. When electrical load variations were coupled with high temperature, high-power devices were found to degrade rapidly. Assemblies in severe industrial and aerospace conditions exhibited the greatest rates of acceleration of failure (Peyghami et al., 2020). These findings affirm the significance of considering multi-stress conditions in real lifetime consideration.

### Findings of Reliability Enhancement

The findings reviewed also give several improvement strategies. Reinforced solder alloys, underfill materials and compliant structures of interconnect usage enhanced resistance to fatigue. High thermal control including heat spreaders, thermal vias and airflow design proved to be effective in minimizing hotspots. Conformal coats that protect were useful in the forfeiture of corrosion in wet environments (Blaabjerg et al., 2020). Embedded sensors were used to monitor in real-time so that failure is detected early before it breaks down in a disastrous manner.

## DISCUSSION

The findings elicit that the rate of deterioration in electronic assemblies increases faster when they are put in dynamic stress conditions and therefore more combined approaches ought to be used in assessing the reliability. Results show that thermal fatigue and damage caused by vibration are the major sources of failure particularly in high-density circuits and solder joints. The analysed articles demonstrate the developments in the modelling tools, where Weibull analysis and Arrhenius based models are still common in lifetime prediction. Physics-of-failure and simulation-based methods provide more information on the evolution of failures, which proves that predictive accuracy is enhanced when the evolution of the failure is modelled with the help of the empirical information.

Nonetheless, studies do not provide coherent frameworks which can explain multi-stress interactions, field uncertainties and long-term ageing behaviour. The fact that machine learning models are in use implies that there is an increased movement towards predictive maintenance, although their application in the field requires access to large reliability datasets (Jiang et al., 2019). This discussion indicates that future research can be conducted to come up with hybrid forms of reliability models that would incorporate the elements of statistical prediction, simulation, and real-time monitoring.

## CONCLUSION

This report has discussed reliability modelling and failure analysis of electronic assemblies under dynamic loads in the presence of thermal cycling, vibration and electrical variation on degradation. The literature review and secondary analysis revealed typical failure mechanisms, designing methods, and possible ways of improvement. The research found out that simultaneous stressful environments cause failures to happen faster as compared to exposure to a single stress and that reliability prediction is better when both simulation and statistical models are combined.

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