Extreme Environments

Executive Summary

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The entire paper focuses on the nature of engineering in the context of extreme environments. It also goes into depth about risk assessment and risk mitigation techniques such as test and evaluation (T & E) and Model and Simulation (M&S). System performance assurance and operation reliability improvements are also discussed.

Introduction

Extreme Environments are any environments that satisfy any of the following criteria:

1. Little previous knowledge on the system will function under extremes
2. Abnormal exposure to cold, heat, pressure, corrosives, radiation, moisture, etc.
3. Exposure to extreme fluctuations in temperatures
4. Time critical

If a system is not supportable or repairable after deployment, it becomes even more extreme. Moreover, extreme conditions not only expand the requirements themselves, they also expand the project scope because engineers have to better understand the environment and the interactions within. There are also many limitations when it comes to testing for an extreme environment. Test resources are usually for typical environments, and resources for extreme environments are usually limited or unavailable. They also tend to make schedules, costs, and requirements for resources rise.

The paper goes on to list some examples of engineering projects done in the Advanced Physics Laboratory (APL) that are required to operate in extreme environments such as the implantable insulin pump, deep ocean sensing systems, electronics in rail gun projectiles, interplanetary space missions close to the Sun, and body armor.

Strategies for Assessing and Managing Risk

Determining risks early on a project is critical and necessary. Some strategies include brainstorming, design reviews, and baselines against previous projects. Strategies for assessing and managing risk include environmental awareness, system design, T&E, and M&S.

System Design as a Risk Mitigation Strategy
Engineers can improve system design by adding components that protect the system from extremes.

Accelerated Testing
Accelerated testing is used to estimate the useful life of a critical component and subsystems, putting into consideration factors that accelerate decline such as temperature, voltage, mechanical load, thermal cycling, humidity etc., under the assumption that failures are the same when using accelerated rates in a short time and normal rates over a longer period.

Material Characterization
Selecting the proper materials can also be the defining factor in a system's success in an extreme environment. Some things to consider include things such as elastic modules, coefficient of thermal expansion, yield strength, etc.

M&S as a Risk Assessment and Risk Mitigation Strategy
This is very useful when accelerated testing is not possible. Examples include numerical simulations using finite-based multiphysics models, analytical models (useful when physical constants vary highly), and the Monte Carlo (useful when model parameters are highly random).

Physics of Failure Method
The above uses model and simulation to design systems that are reliable by modeling root causes of failure such as fatigue, radiation, corrosion, etc.

Risk Mitigation Planning

Sometimes, engineers also come up with alterative designs or "Plan B," but downsides include higher costs, as these alternatives also need to be tested, etc. Looking out for critical items that can bring a whole system down is also crucial; these can signify a need for redesign.

Modeling and Simulation
M&S is useful when not all data is present; however techniques often use massive amounts of computer resources. Therefore, engineers must really ask themselves if M&S is the solution. Coupling it with T&E usually leads to better results.

Testing and Evaluation
T&E is usually done during the last phases and is very extensive. Because it can make up a majority of development costs, it needs to be well thought out starting with a Testing Master Plan. This should detail the entire process including the goals, features to be tested, features to be excluded, testing methodologies, fabrication of test articles, procurement of resources, etc. Furthermore, results must be unambiguous and consistent; it must also have an exit criteria.

T&E and M&S are very closely related. Solid M&S results can help guide testing and vice versa. Iterative processing of the two results in much better system models.

Mars Science and Laboratory Rover Actuator Electronics

The paper then goes on to illustrate two examples that utilize the risk mitigation and assessment techniques previously described. The first is by the Jet Propulsion Laboratory (JPL) Mars Science Laboratory (MSL) program. The main focus is a rover that cans assess life on Mars. JPL came to APL to help make sure that the rover's unpackaged actuator electronics would survive Mar's extreme temperatures which can range from -127F to +30F. Together with the University of Maryland's Center for Advanced Life Cycling Engineering (CALCE), APL used the physics of failure methodology to determine suitable materials and package techniques. They also used material characterization and finite thermomechanical simulation models in

the study.

Testing and Simulation in a Projectile Environment

The next example studied a human surrogate torso to assess techniques that can predict human injury from non-penetrating ballistic impact. Facilitated by APL and funded by the Defense Advanced Research Projects Agency (DARPA), it used a combination of T&E and M&S.

They used experimental surrogates (a physical torso model) that was tested under ballistic impact. The results where then compared to a FEM model. They also used material characterization ensure proper materials were used to create the most accurate FEM human torso. Moreover, they used iterative dynamic simulation and software to create better simulation results.

Summary

Guidelines for designing systems that must operate under extreme environments where outlined in this paper. They include the physics of failure method for risk assessment and T&E, as well as M&E for risk mitigation. Two examples were also given to illustrate the techniques in a real world setting.

The Advanced Physics Laboratory has been investing in M&S and T&E heavily, especially in the recent years. Their expertise in these techniques can equip systems engineers in making informed decisions early on during the design stages, as well as provides them with the knowledge to execute proper risk mitigation for successful systems in extreme environments.