OVERVIEW OF ENVIRONMENTAL REQUIREMENTS PROGRAMS

Introduction:

The Environmental Requirements Program of a flight project is to ensure that the spacecraft and the payload will perform reliably and as required throughout the entire mission lifecycle. Environmental Requirements include both design and verification requirements that are consistent in their detailed specifications and cover ground operations, launch and flight mission environments. Environmental design and test requirements are established early in the project lifecycle prior to the Preliminary Design Review. The requirements are specifically tailored to the needs and characteristics of each project mission. Environmental testing is the predominate design verification approach except where the flight equipment would be unnecessarily damaged by testing or testing is prohibitively expensive and analysis can be used as the verification approach with confidence.

Environmental Requirements Margins:

Environmental design requirements are established to have robust margin over the expected environments that the spacecraft and payload will encounter during the project lifecycle. Margins are very important to compensate for the uncertainties in the environmental modeling and derivation processes. Margins are also important to ensure that the flight equipment performance and reliability are maintained if encountered environmental conditions exceed predictions due to derivation errors and uncertainties or due to changes in spacecraft control capability such as the thermal properties of control surfaces being degraded by contaminates. Robust margins can avoid expensive analyses and risk mitigation when environmental exposures exceed expectations during the flight mission. Cost / risk tradeoffs are required to balance design margins with spacecraft mass and power impacts. Example environmental requirements test margins are defined in Appendix A of the MRO Preliminary Environmental Requirements and Estimates, D-20241. NOTE: The detailed requirements in the MRO reference are unique to that Project so they should not be assumed for GMO. The format of the requirements can be used for GMO, however, which is the intent of using them as a reference.

Environmental Interfaces With the Spacecraft Developer:

It is assumed that the spacecraft developer will define the predicted environments at the interfaces between the spacecraft system and the engineering or payload assemblies since these environments will be driven by the system interaction with the launch and space mission environments. For instance, the launch vehicle will produce launch dynamics environments that the spacecraft will respond to. These responses will be dependent on the system design that will influence its susceptibility to acoustics as an example. Therefore, the interface environments must be defined by the spacecraft developer with appropriate margins applied as discussed above.

Primary Environments to be Considered in the Development of Flight Spacecraft:

Ground Operations and Flight Hardware Environmental Conditions- The environments that are imposed on flight equipment during ground operations should be controlled to maintain them at levels below the flight environments so they do not influence the design requirements. In some cases such as ground transportation, the shipping containers need to be designed to protect the flight equipment from environments in excess of environmental design requirements based on launch and flight mission environments.

Thermal- Objectives: Define the Thermal Radiation Environments that will influence the thermal response of the spacecraft. Also define the interface temperature requirements for the spacecraft assemblies.

Mission Sources: Direct solar, reflected solar (albedo), and planetary IR which vary with the mission phase. Typical Requirements: Section 4.1, Thermal Radiation and Section 4.2, Assembly Temperatures, of the MRO Preliminary Environmental Requirements and Estimates, D-20241.

Typical Requirements: Thermal radiation values for the different phases of the mission, Solar-Spectral-Irradiance Data, temperature design requirements for the spacecraft assemblies, temperature test levels and durations, system thermal vacuum test requirements, thermal shock (if applicable) and uncontrolled and controlled ground temperature, pressure, humidity requirements are typical requirements to be specified.

Verification: Thermal tests are performed on assemblies, subsystems and the spacecraft system . The tests qualify the flight equipment packaging thermal design, validate the functional design over temperature, screen for latent manufacturing defects and demonstrate robust design . Design and test margins of 20 degrees beyond the allowable flight temperature are common. Since vacuum has considerable influence on the thermal response of flight equipment, it is typically required that thermal vacuum tests be conducted to better simulate the deep space environment. Test durations at stabilized temperature of 144 hours at the high temperature and 24 hours at low temperature are common at JPL.

Dynamics- Objectives: Design and verify the spacecraft and its assemblies for the launch environments that will be imposed on them including acoustics, shock, vibration and quasi-static loads.

Mission Sources: The Acoustic environment occurs at launch liftoff and in the transonic/maximum dynamic pressure regime after liftoff. This environment is very dependent on the launch vehicle and the launch pad configuration. The predominate shock environments are from the firing of pyrotechnic devices during separation of the spacecraft from the launch vehicle and from pyrotechnic firings on the spacecraft itself. The random vibration environment is transmitted from the launch vehicle to the spacecraft as a result of launch vehicle, adapter and spacecraft structure responding to the acoustic impingement. The quasi-static loads result from the combination of quasi-steady accelerations due to launch vehicle thrust and low frequency vibrations due to launch vehicle transient and random excitation events.

Typical Requirements: See Section 3 of the MRO Preliminary Environmental Requirements and Estimates, D-20241. Random vibration acceleration levels and frequency spectra and test duration or sweep rate, pyrotechnic shock spectra, acoustics spectra and quasi-static loads are typical requirements. Design/test margins are important due to uncertainties in the predictions and it the test control. Three to Four dB margin over the acoustics maximum expected flight levels (MEFL) and 3dB over the MEFL on the random vibration power spectral density plot are typical margins. A margin of 1.4 on the shock MEFL is typical.

Verification: Acoustic, shock and vibration tests at the assembly, subsystem and system levels. Acoustic tests are performed only on assemblies that have a large surface area to mass ratio. The quasi-static loads requirements are verified by analysis and test of spacecraft structure.

Natural Space -Objectives: Ensure that the spacecraft will perform as required within the natural space radiation and micrometeoroid environments.

Mission Sources: The major contributors to the Mars radiation environment are the Galactic Cosmic Rays (GCR) and Solar Proton Events (SPE). These two environments include Total Ionizing Dose (TID) effects, Single Event Effects (SEE), Displacement Damage, and Non-Ionizing Energy Loss Effects. The micrometeoroid environment is an omnidirectional spectrum in space.

Typical Requirements: These environments are highly variable so that is common for the project to assign a Radiation Design Margin (RDM) to account for uncertainties. Typically at least a factor of two is specified. The primary radiation environment of concern to a Mars mission is the solar activity and the principle source of radiation damage is the Solar Proton Event. Each mission should estimate the likelihood of a given flux level being observed as a function of the mission's duration versus the eleven year solar cycle. The JPL SPE model splits the 11 year solar cycle into 4 inactive and 7 active years. In addition to dose, the SEE is critical to determining effects of the radiation environment on a space mission. These environments are typically characterized in terms of Linear Energy Transfer (LET) (MeV cm^2/mg). The micrometeoroid environment is specified by defining the expected mission omnidirectional mass fluence. Example natural space environment requirements are contained in Sections 4.4 and 4.5 of the MRO Preliminary Environmental Requirements and Estimates, D-20241. Spacecraft charging related design requirements in the space radiation environment also need to be established.

Verification: Verification of compliance with natural space requirements is accomplished primarily through analyses, however, some testing may be required for natural space environments. Some examples of consideration for test are:

- Untested materials
- New electronic parts that have not been characterized relative to ionizing dose, displacement damage, and susceptibility to SEE.
- Spacecraft charging effects
- Micrometeoroid effects on materials such as thermal control surfaces and pressure vessels

Electromagnetic Compatibility (EMC)-Objectives : Ensure that the spacecraft system will perform as required during pre-launch, launch and mission operations without unacceptable degradation due to electromagnetic interference.

Mission Sources: EMC design and test requirements need to account for the EMC environments and constraints generated by the launch site such as ground based radar, launch vehicle and by the spacecraft.

Typical Requirements: The design requirements need to account for electromagnetic emissions, electromagnetic susceptibility, DC (static and slowly varying) magnetic fields, and electrostatic discharge (ESD) resulting from spacecraft charging on ungrounded surfaces or ungrounded materials internal to the spacecraft.

Verification: EMC tests are performed at the assembly and at the spacecraft system configuration levels. The hardware levels to be tested need to be determined for each project. Typical tests include:

- Electrical Bonding and End Circuit Isolation
- Radiated Emissions
- Radiated Susceptibility
- Conducted Emissions
- Conducted Susceptibility
- DC Magnetic Field Susceptibility
- DC Magnetic Field "Emissions"
- Electrostatic Discharge

Example requirements are specified in Section 2.3 of the MRO Preliminary Environmental Requirements and Estimates, D-20241.

Payload Generated EMC Fields-The spacecraft must be designed to comply with the EMC constraints placed on it by the payload to avoid interference with the operation of the payload. These requirements will include both conducted emissions and radiated emissions constraints that are dictated by the conducted and radiated susceptibility of the payload.

Spacecraft and Launch Vehicle Generated EMC Fields-These requirements must be specified to the payload to ensure that it is designed to be compatible with the conducted and radiated emissions that are associated with the basic spacecraft and launch vehicle operation. These are functions such as the telemetry systems that must operate at specified frequencies.