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Quality and Reliability in Space Systems - An Overview

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Abstract: The significance of Quality and Reliability Assurance in modern engineering became really highlighted with the growth of space activities. It would be only apt to term the Reliability as the greatest spin off from space science and technology. Space systems in general (both launch vehicle and spacecraft), are distinguished by their characteristic of unattended operation, with a high degree of Reliability. While, the broad requirements with respect to Reliability and Quality Assurance programme are similar for both launch vehicles and spacecrafts, the specific requirements in each of the disciplines of R & QA vary due to their distinct operational profiles. Unlike launch vehicles, which are single shot missions, spacecraft need to operate for long periods (12-15 years) with minimum intervention from ground, under hostile space environment.

The paper details the specific R & QA provisions / requirements to be adopted for successful realization of subsystems and systems for a spacecraft project. Design assurance methodologies, Reliability Analyses like Derating analysis, FMECA, FTA, Worst case circuit analysis, Sneak Circuit analysis, Reliability apportionment / prediction, Test & Evaluation, Non-conformance control, Reviews etc are covered in addition to conventional Quality Control activities like Parts/Materials/ Process control.

Keywords: *Quality, Reliability, Spacecraft, launch vehicle, Space environment, life assurance, environmental testing, non-conformance*

1 INTRODUCTION

There is no discipline in today's world, where the word "Quality" does not find a mention. Be it in the field of Engineering, Medicine, Law, Business Administration and even entertainment the importance of quality cannot be over emphasized. In today's competitive world, wherein the market rules over every one, and "Customer is the king", maximum attention is being paid to ensure highest quality in all the aspects of business like Research, Design, Development, Production, Marketing, Service, Customer interaction etc.

While this focus on quality is relatively new to the commercial establishments, which are primarily driven by competition and globalization, there are some traditional disciplines of engineering / research, which had the ingredients of quality and reliability built in to their programmes almost from the times these programmes are born. Especially in Defence and aerospace sectors, quality and reliability were built into the system development cycle since their inception and it can be said that most of the modern concepts in quality and reliability owe their origin to developments from the Defence and Aerospace Sectors.

The significance of Quality and Reliability Assurance in modern engineering became really highlighted with the growth of space activities. It would be only apt to term the Reliability as the greatest spin off from space science and technology. Space systems in general (both launch vehicle and spacecraft), are distinguished by their characteristic of unattended operation, with a high degree of Reliability. While, the broad requirements with respect to Reliability and Quality Assurance programme are similar for both launch vehicles and spacecrafts, the specific requirements in each of the disciplines of R & QA vary due to their distinct operational profiles. Unlike launch vehicles, which are single shot missions, spacecraft need to operate for long periods (12-15 years) with minimum intervention from ground, under hostile space environment. This paper deals with specific R & QA provisions / requirements to be adopted for successful realization of subsystems and systems for any Hi-Rel programme. In order to explain some methodologies, the examples of space systems have been liberally made use of. However, it may be noted that the governing philosophies will be more or less identical in any Hi-Rel applications.

II DEFINITIONS

Before expanding further on various aspects of R&QA, a brief definition of quality and reliability are indicated.

Quality: The oldest and perhaps the simplest definition of quality is "Fitness for use". This simple definition has metamorphosed into various forms over time and the most acceptable measure of quality in the modern world is "Customer Satisfaction".

Reliability: Reliability is defined as "the probability that a system will operate satisfactorily for a given period of time under specified environment".

The underlining factors of reliability are:

- **a)** Satisfactory operation (Mission goal)
- **b)** Given period of time (Mission time)
- **c)** Specified environment

Product effectiveness: The overall capability of a product to meet customer objective is called product effectiveness. The ultimate goal of any product or system is its ability to perform its intended function at affordably lowest cost. Overall cost includes purchase price, operational cost, maintenance cost and repair cost. Product effectiveness is a function of many product attributes and external factors.

III NEED FOR RELIABILITY

The need for highly reliable systems is governed by the following factors:

- ➢ Economic view point
  - Replacement cost
  - Loss due to disrupted service
- ➢ Safety
- ➢ To minimize schedule delays
- ➢ To avoid inconvenience
- ➢ To ensure customer satisfaction
- ➢ National pride / prestige
- ➢ National security

Reliability engineering has been developed in response to the need to understand, mathematically model and control various risk factors that influence product effectiveness. The perceived risks are governed by various pressures like Developmental Risks, Legal / Statutory factors, Public Liability, Warranty and Safety considerations, Competition, Market Pressure, Management emphasis, Customers requirements etc.

Reliability engineering methods can be applied to design, development and management to control the level of risk. Hence, the application of reliability has now become an essential ingredient of modern engineering.

IV DEVELOPMENT OF RELIABILITY ENGINEERING - MILESTONES

Some of the milestones in the development of Reliability Engineering are given below:

- ➢ Reliability engineering as a separate engineering discipline originated in the United States during 1950s.
- ➢ Setting up of AGREE in 1952 (Advisory Group on Reliability of Electronic Equipment).
- ➢ The Department of Defence (DOD) issued the AGREE Report on testing as MIL-STD-781-Reliability Qualification and production approval tests.
- ➢ AGREE and Reliability programme concepts were adopted by NASA in 1965.
- ➢ DOD issued MIL-STD-785-Reliability programme for systems and equipment.
- ➢ UK issued Defence Standard 00.40-The Management of Reliability and Maintainability.
- ➢ BS 5760 guidelines on Reliability of Systems, equipments and components were issued in 1981.

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- RAM (Reliability And Maintainability Symposium) are conducted every year in Europe and USA from 1970 onwards.

V R&QA ORGANIZATION

The highest authority responsible for implementation of quality programmes is the head of the organization. Further, depending on the size of the organization and criticality of the systems being developed, normally matrix management set up is followed. Under this, each centre under the organization will have a dedicated R&QA team supporting overall QA activities of the centre. Also, each specific project being managed with in the centre will have focal points from QA reporting to respective project directors for coordinating the QA activities across various divisions / groups contributing to the realization of project.

VI MAJOR DISCIPLINES OF R&QA

Following are the major disciplines of R & QA to be implemented for any Hi-Rel programme:

a) Parts, Materials and Process (PMP) Control
b) Design Assurance
c) Reliability Engineering
d) Test and Evaluation
e) Software Assurance
f) Non Conformance Management
g) Configuration Control

Before drawing up an elaborate R & QA plan, basic understanding of the system intricacies and the environment under which it operates is essential. As an example of this approach, classification of space systems, their associated intricacies and brief description of space environment are highlighted here.

VII SPACE SYSTEMS AND ASSOCIATED INTRICACIES

Space Systems can be broadly classified into any of the following four categories:

a) Launch Vehicle Equipment: On-board systems flying as part of launch vehicle.

b) Spacecraft equipment: On-board systems flying as part of spacecraft.

c) Ground Support equipment: Ground Systems which help in operation / test / launch of launch vehicles and spacecrafts.

d) Ground Station Equipment: Equipment installed in ground stations to support the mission operations during vehicle launch / spacecraft on-orbit operations.

Equipment in each of these categories have some unique requirements, which have to be considered while drawing the R&QA programme requirements. Some of these distinct features with respect to each of these systems are highlighted.

Launch Vehicle Equipment: Being a one-shot mission, following special features / characterize the launch vehicle equipment.

- Ability to perform right the first time in full mission configuration.
- Auto reconfiguration features to take care of in-flight failures (No real time intervention from ground possible). The only intervention from ground is to destroy the vehicle, in case the vehicle is steering away from the designated trajectory, and likely to pose safety hazard.
- Inadequate testability: Several of the vehicle systems can be tested in full configuration only during flight.
- Dependence on stringent QC measures: Units like pyros that are meant for final flight cannot be tested even partially before launch.

All the systems to perform and meet specifications during harsh vibro acoustic environment during launch.

Spacecraft equipment: With life times of 12 to 15 years for new generation spacecrafts, following special features characterize the spacecraft equipment;

- Ability to perform for prolonged durations with minimum intervention from ground. However, unlike launch vehicles, some minimum assistance from ground can be provided in case of contingencies for spacecraft.

- Equipment should be capable of withstanding harsh space environment viz. Temperature extremes, ultra-high vacuum, zero-g etc.
- Protection against effects of particulate radiation. (Total does effects, Single event effects etc.,)
- Designs to take care of charge build up phenomenon (up to 20KV) and should be capable of withstanding electrostatic discharges (ESD) effects.
- Equipment to withstand vibro – acoustic regime imposed by launch vehicle. (However only few systems like Gyros, Communication equipment need to perform during launch, other systems like Payload etc., will be powered OFF).
- Limited testability in final configuration for some electro-optical and electromechanical systems due to their interactions with external factors like sun / moon interference, reflections from optical surfaces (attitude sensors) or inherent configuration limitations, (e.g., solar array drive assembly).

Ground support equipment: The equipment has to support launch vehicle / satellite evaluation without any malfunction, whenever called for. Usually, this equipment will have spare units, which are ready for use on demand. However, it should be possible to replace this equipment on demand at the earliest without affecting the sequence of operations in order to meet the launch schedule. The equipment design has to be modular in nature to limit the number of spares and reduce the repair time (MTTR).

Ground station equipment: The ground station equipment has to support mission operations of both launch vehicle (during launch) and spacecraft (throughout its mission life). Also at centres, where data products are generated, the equipment should be capable of producing the desired products in minimum turnaround time. Availability considerations play a major role in design of these ground station equipment / complex.

VIII SPACE ENVIRONMENT

The spacecraft equipment have to be designed to withstand the worst case conditions of environments arising out of (a) Transportation, handling and storage, (b) Pre-launch phase, (c) Launch phase and (d) Orbital phase

Among these, (a) and (b) are characterized by temperature, relative humidity and mechanical loads during transportation. In general, these loads are not as severe as in launch / orbital phase. Typically, temperatures will be around 20 ± 3° C, RH around 55 ± 5% and expected vibration levels are around ± 2 g. The launch environment is characterized by acoustic noise, random vibration, sinusoidal vibration, shock, sustained acceleration, decreasing pressure and temperature.

The most important environment, a spacecraft has to withstand is during its orbital phase, which consists of the following:

Weightlessness (or zero-g) Due to finite dimension of spacecraft, the sum of all the forces acting will not be zero and residual-g environment will prevail. Apart from gravity, aerodynamic drag, solar radiation pressure and magnetic disturbance militate absolute weightlessness and have significant effect on attitude control system and behavior of deployment mechanism.

Temperature During on-orbit, the temperature of spacecraft depends on, (a) Solar radiation and earth albedo, (b) Thermal radiation from earth, (c) Thermal radiation to earth, (d) Thermal radiation to free space and (e) Heat generated by spacecraft due to its internal dissipation. Typically, electronic packages inside spacecraft are controlled between 0-40° C and outside elements exhibit wider variation (e.g., Solar panels vary between –100° C to +80° C typically)

Vacuum The pressure range is between 10^{-10} to 10^{-16} torr (1 torr = 1 mm Hg) and is a function of spacecraft altitude. However, considering the molecular mean free path, a pressure level of 10^{-4} to 10^{-5} torr is adequate for simulation purposes in most cases of ground testing

Particulate radiation It consists of (a) Trapped particles (Van Allen belts), (b) High energy particles – solar protons, (c) Cosmic rays, (d) Solar wind – continuous emission of plasma, (e) micro-meteoroids and (f) Solar radiation pressure.

Magnetic fields Due to Geomagnetic field and fields of spacecraft elements itself.

IX MODEL PHILOSOPHY

A spacecraft subsystem / system has to undergo several stages like development / bread boarding, design qualification, flight acceptance before being cleared for actual flight.

To accomplish this, following model philosophy is adopted.

Development/Bread Board model This is applicable only to new designs, the primary focus being on conceptual validation. It need not necessarily represent full flight configuration and can be limited to the developments, which need conceptual validation.

Structural / Thermal model This is normally applicable at system level and is helpful in structural / thermal design validation. Most of the subsystems are simulated by their physical properties and need not contain functional units.

Qualification / Engineering model This model is built to establish design margins with respect to environmental conditions. The purpose is to uncover deficiencies in design and qualification and the test levels are not intended to exceed design and safety margin to introduce unrealistic failure modes. At system level, sometimes structural / thermal model and Engineering Model are combined in to one unit, depending on heritage, maturity of design, hardware availability and schedules.

Flight Model This model is intended to fly and the tests are limited to reveal latent material / component and workmanship defects. The secondary purpose is to provide experience on flight model performance under conditions similar to the mission environment.

Proto-flight Model This is a model intended to be used for flight but does not have adequate qualification history. Proto-flight philosophy is adopted wherever,

a) Significant changes have been made on flight model with respect to qualification model

b) It is not feasible to build a separate qualification model due to availability / cost / schedule requirements or practical considerations. (e.g. on experimental payload, which is going to be flown only in one mission)

Here, design qualification and flight acceptance are combined and more severe test levels are imposed than in flight conditions but the test durations are restricted to those of flight (mainly applicable for mechanical tests).

X PARTS, MATERIALS AND PROCESS CONTROL

Parts procurement is carried out considering the mission requirements (LEO Vs GEO), mission criticality (experimental Vs operational), mission life etc. In general, only Parts which are listed in preferred Parts List / Qualified Parts List (PPL / QPL) are used.

Following methodology is adopted for component procurement/screening/usage.

- Component procurement specifications are generated by Components Division based on MIL / ESA specifications
- Technical Evaluation Committee (TEC) reviews the quality aspects
- QA aspects for Special Parts (e.g, ASICS / CCDs) are reviewed through Request for Proposal (RFP) Review Committees
- Parts Review Board provides policy guidelines
- The quality level of Parts to be procured

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Passive Components: Established Reliability (R level or better)
Discrete Semiconductors: MIL-S-19500 JAN S/ESA-SCC-5000 level B
Microcircuits: MIL-M-38510 class `S'/QML Class V / ESA-SCC 9000 level B
Non-standard parts: Source Control Drawing (SCD) in line with MIL-STD-975/SCD of other spacecraft users

- Component screening is carried out as per MIL-STD-883 for microcircuits and as per MIL-STD-750 for discrete devices
- For devices not available to Class `S' level, the parts heritage / basic quality level and radiation sensitivity are reviewed and additional tests like incremental screening tests, life test, Qualification / QCI tests (environmental / mechanical), Destructive Physical Analysis (DPA) and Radiation tests are carried out before deciding on their use.
- Components should be able to withstand Total dose (ionization) effects/single event effects with Linear Energy Transfer (LET) threshold: 40 MeV-cm^2/mg, and immune to latch up. Total dose analysis and estimation is carried out and local shielding provided wherever necessary.
- Components stored for more than 5 years undergo relifing tests consisting of visual examination (100%), electrical measurement (100%), seal leak test (samples), solderability and DPA (samples).
- Failure Analysis of Parts will be carried out to find out the failure cause for components failed during various phases of screening / testing. Findings are fed back to manufacturer / T & E / design teams for suitable action.

Materials Control Selection criteria for materials used in spacecraft include, functional suitability, Reliability, environment, availability, compatibility, fabricability, cleanliness, mass optimization, mission life and cost.

- In general, the material should meet the out-gassing requirements of total mass loss (TML) <1% and collectable voltatile condensable material (CVCM) < 0.1%
- A declared material list (DML) is available and use of materials from DML is encouraged.
- For every new material, qualification tests will be tailor made and its mechanical, thermal and chemical properties are evaluated before inclusion in DML.

Process Control Processes to be used during fabrication of spacecraft hardware should have been qualified and included in approved parts list.

- New processes to undergo process qualification and evaluation tests, which include temperature cycling, vibration, and other application specific tests.
- For various processes (electrical) & mechanical), QC guidelines, requirements and accept / reject criteria are generated.
- Traceability of all parts and materials maintained.
- Flow charts / process identification document (PIDs) are prepared for all the processes
- All personnel involved in fabrication and inspection are trained and certified.
- Fabrication facilities are periodically audited.
- Wherever external vendor carries out activities, vendor evaluation and line certification are carried out.
- A stringent Electro Static Discharge (ESD) Control program is implemented and control measures for each lab are identified. This includes usage of materials and equipment necessary for ESD Control, Training of Personnel, Periodic ESD audits, and establishment of Static Sensitive Zones (SSZ) in each lab.
- Cleanliness of work places is essential and a strict control mechanism is implemented for meeting following requirements.

Class – C – 100,000 Particles/cft
- for subsystem wiring / assembly / test
- for spacecraft integration / checkout

Class – B – 10,000 Particles/cft
- for electro optical subsystem fabrication

Class - A – 100 Particle / cft
- for assembly of bearings / precision Mechanical parts and optical assemblies

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XI TEST AND EVALUATION

The primary objectives of Test and Evaluation programme are,

a) To demonstrate full compliance of system performance under prescribed environmental conditions
b) To verify design margins through qualification testing
c) To weed out workmanship defects using Environmental Stress Screening (ESS)
d) To provide Reliability demonstration for specific elements as applicable (EEDs)
e) To demonstrate that wear out mechanism does not affect functionality during mission life through life testing and
f) To generate adequate test / calibration data for use in mission operations.

The typical test sequence for a subsystem includes Functional performance, EMI/EMC tests, ESD tests (for GEO), temperature soak, post conformal coating / potting / radiation shielding test, sine vibration, random vibration, temperature cycling, thermovac soak, power burn-in (for RF systems) and final ambient performance test. Of these tests, EMI/EMC/ESD and sine vibration tests are done only on qualification / engineering model units.

The typical test sequence for spacecraft includes subsystem integration, assembled IST, thermovac performance, thermal balance test (for QM/new thermal design), appendages integration, end to end checks for AOCS, TTC, payload and RCS, pre-dynamic deployment and alignments, sine vibration (based on launch requirement), acoustic test and post dynamic IST, deployment, alignment, RF radiated tests and RCS tests.

The environmental test levels are arrived at based on the subsystem locations within spacecraft and its mission profile. An Environmental Test Level Committee (ETLC) is constituted for each project, which recommends test levels. EMI/EMC tests are carried out as per MIL-STD-461C. Adequate test margins are adopted over the predicted levels. The margins are kept higher for Qualification and proto flight models, and flight models are tested for acceptance levels with lesser margins over predictons. Several test limitations are encountered due to simulation uncertainties (sun / moon intrusion, FoV clearances, interaction between moving elements, full power radiation) and in such cases, adequate analysis / computer simulations have to be carried out for enhancing the confidence. Some aspects like spacecraft dynamics (flexibility modelling), sizing of solar sail etc. are totally dependent on analysis and cannot be validated by tests. Non-availability of adequate life test data before flight for elements like wheels, where accelerated life tests are not possible forms another limitation. Some elements like EEDs, deployments etc., can be tested in final configuration only in flight. Adequate analysis / verification of quality (VOQ) concepts and sound engineering judgment have to be adopted in such cases.

XII RELIABILITY ANALYSIS

- Reliability activities for spacecraft consist of Reliability goal fixing / apportionment, Reliability Prediction, Parts Stress Derating Anlaysis, Failure Mode Effects and Criticality Analysis, Fault Tree Analysis and preparation of critical item lists.
- Various modes of redundancy are employed in spacecraft subsystems to avoid single point failures and enhance reliability. Stand by redundancy is adopted for wheels, Gyros, SADA electronics, sensors and payload elements. Active parallel redundancy is incorporated for power control and management, TT& C, AOCE etc. Among this k out of n redundancy schemes are adopted in those cases where one to one redundancy cannot be adopted due to configuration constraints / real estate requirements and cost considerations. This technique is adopted in wheels (3 out of 4), Solar Array, Battery etc. Majority voting logic is implemented for some safety features in Power Systems and in AOCE software modules to take care of single event upsets.
- Due to configuration constraints, redundancy cannot be provided for SADA bearing shaft, propulsion tanks, latch valve LVG, RCS filters,

several Mechanisms, Payload Rx Antenna and feed, VHRR Scan Mechanism etc. These are identified as critical items and very stringent Quality Control Plan is drawn and adopted for realization of these elements.

- Following measures are adopted, in the chronological order specified, to improve reliability of a unit, wherever it fails to meet the desired goals: (a) simplify the design (b) usage of higher quality parts (c) Increased margins for derating (d) Redundancy incorporation and (e) tighter control on environment under which the unit operates.
- Several mathematical models are available for failure rate modeling and reliability computation. The most widely used distributions are exponential distribution (for electrical systems) and Weibull distribution for (mechanical systems). The mathematical treatment of each of these distributions is beyond the scope of this article.

XIII DESIGN REVIEWS

- ➢ Design review is a multi-discipline synergistic tool to assure that each design has been adequately studied to identify possible problems. The intent of such review is to provide assurance that the design is capable of meeting the specified requirements.
- ➢ The review is accomplished by representation from various technical disciplines, reliability engineering, academicians, other technological organizations and user community.
- ➢ Design reviews are interactive. They are repeated at appropriate stages in the design process, to evaluate achievement of reliability requirements.

Following reviews are held based on the development stage / maturity of the hard wares:

- Base line design review (conceptual)
- Preliminary design review (to choose the final option)
- Critical design review (after engineering model development)
- Pre-shipment review (flight model performance)

XIV NON-CONFORMANCE MANAGEMENT/CONFIGURATION CONTROL

During product development life cycle, several non-conformances will be faced at various stages like Design, Parts procurement, Fabrication, Testing and Service.

The failures could be due to:

- Design deficiencies
- Component / material defects
- New environments
- Deficiency in test program (test induced)
- Poor communications (interface / configuration control)

In all the cases, an effective closed looped system called Failure reporting, analysis and corrective action system is adopted to manage the observed non-conformances. When a non-conformance cannot be resolved by any of the existing systems, and has to be lived with it is referred to a waiver board, which decides the final course of action.

Configuration Management / Control: Configuration management and control are essential in any high-rel programme. An effective configuration control mechanism ensures good traceability, aids documented production and guards against repeating mistakes. The implementation of configuration control mechanism depends on the size/nature of the project and has to be tailor made based on specific requirements.

XV SOFTWARE ASSURANCE

The role of software in on board as well as ground systems is growing at a very high rate and hence software assurance plays a vital role in ensuring the reliable operation of space systems. Towards achieving this, all the centres have to establish software assurance cells / sections / groups and all on board / ground software have to follow a pre-defined

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development process and meet the laid-out guide lines.

Some of the important milestones in software development life cycle are:

- Software requirements identifications / review
- Software Design / Review
- Software testing at various phases (white box, black box)
- Code walkthrough of the final code
- Software configuration management
- Quantification of software reliability (metrics).

XVI R&QA PRACTICES - DIFFERENCES IN APPROACH / PRACTICE BETWEEN DEFENCE / AEROSPACE AND OTHER ESTABLISHMENTS:

Defence / Aerospace establishments being of paramount importance to the national endeavour and also due to non-repairable nature of space hardware, several differences exist between R&QA practices followed by Space Industry vis-à-vis non-space industry.

Few aspects are highlighted.

Limited use of statistical quality control concepts: Normally emphasis is laid to screen 100% of the components for use in space hardware and test the complete hardware through its expected environment. Only, wherever configuration constraints do not allow 100% testing, statistical quality control concepts are made use of (eg. Pyros).

Usage of high-rel components: As the systems have to perform unattended for very long periods (15 years) or work first time right, hi-rel components have to be used to realize space equipment / system.

Derating Parts have to be operated well below their rated values to reduce the failure rate and meet the reliability goals.

Redundancy: Normally all the sub-systems in a space system incorporate redundancy (except those places, where configuration constrains do not permit redundancy to be incorporated. e.g. Spacecraft structure, rocket engine) to take care of single point failures (i.e. any one component failure should not lead to mission failure). Consequently, one has to perform failure mode effects analysis (FMEA), Fault tree analysis (FTA) to assure the effectiveness of redundancies provided.

Test facilities: The testing of space hardware in ambient and environmental conditions is quite complex and needs extensive range of test facilities. The cost of testing forms a significant percentage of any space mission, specially when cost of test set up build up is taken into account. Some of the important test facilities include static test facility, acoustic test facility, large space simulation chamber, compact test range etc.,

Significant role for simulation studies: Inspite of enormous efforts / investments in testing, all the systems cannot be validated in full during ground testing. A large dependence on modelling / simulation / mathematical analysis is imperative in any space system realization.

XVII CONCLUSION

The current spacecraft industry is witnessing revolutionary trends in system realization due to user demands, obsolescence of technology, rapid strides in miniaturization efforts and global competitiveness. Consequently, technology inversion (Development Vs User demands), complexity inversion (space systems Vs ground systems), small / micro satellite efforts, coupled with the need to produce systems, ***faster, cheaper and better*** are putting a lot of pressure on conventional R & QA methodology and are demanding a re-look at the mantras of heritage, qualification testing, use of space grade components etc. Accordingly, concurrent engineering practices are being employed in system realization. There is large research going on with respect to usage of commercial off the shelf (COTS) parts and use of plastic encapsulated devices. Qualified manufacturers list (QML) approach has already been accepted industry wide.

Adherence to designing to cost, batch qualification techniques, optimised test sequences and schedules, need based review mechanisms, optimised provision redundancy, avoiding traditional paper work etc., would be the key factors, which are going to be intensely debated in this emerging practical concept.

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