Quality Management – ISRO`s Experience

G Madhavan Nair
Chairman, ISRO

(Talk delivered at National Convention of the Indian Institution of Industrial Engineering –Quality Management in the 21st Century on September 24, 2004)

1. Introduction

The Indian Space Research Organisation (ISRO) has the mandate to provide reliable and uninterrupted services to the country in telecommunications, TV broadcasting, meteorology and remote sensing applications. The Indian Space Programme which had a modest beginning in late 60s aimed at achieving the above objectives through development and application of space technology and space sciences for the socio economic benefit of the country, has spearheaded the development of sounding rockets, satellite launch vehicles, communications, remote sensing and scientific satellites and a host of systems related to ground support equipment. Over the years, capability has been established to design and develop highly advanced remote sensing and communication satellites. Capability has also been established to design, develop satellite launch vehicles for placing remote sensing satellites and 2 tonne class communication satellites in orbit.

Today, ISRO has sophisticated remote sensing and advanced communication satellites in orbit. Resourcesat-1 the most advanced remote sensing satellite with a multi-spectral resolution of 5.8 meters along with IRS 1C, 1D, IRS P3, P4 have become the mainstay of National Natural Resources Management system. IRS satellite supply remote sensing data not only to users in our country but also to large number of users all over the world through several ground stations located in various parts of the globe. INSAT system with 7 satellites in orbit with about 135 transponders has been meeting the country`s telecommunication, TV broadcast and meteorological needs. Polar Satellite Launch Vehicle (PSLV) with seven consecutive successful flights and Geo-synchronous Satellite Launch Vehicle (GSLV) with two successful flights have placed India in the elite club of countries which possess such capability. PSLV has also launched satellites for Germany, Belgium and Korea.

Space system is the product of a variety of engineering disciplines. Even though, these disciplines are based on a number of conventions adopted for terrestrial systems, what distinguishes their application to a space system is the characteristic of unattended operation, with a high degree of reliability, in a hostile environment of space. Reliability and Quality Assurance practices which grew along with space activities have been one of the greatest spin-offs from space technology.

In ISRO, organized quality assurance practices started as a modest programme of test and evaluation of electronic systems for sounding rockets during the early years of Indian Space research at the Thumba Equatorial Rocket Launching Station (TERLS) at Thiruvananthapuram. Today, in tune with the more complex and advanced programmes of the organization, the role of Reliability and Quality Assurance (R&QA) aspects has also expanded in scope and importance. Each of the ISRO Centres has an organized group of technical staff looking after the R&QA requirements of the major projects. These groups are headed by a senior staff member reporting directly to the Director of the Centre. Over 1000 technical personnel i.e , about six percent of the total strength of the organization are engaged full time on various quality related activities; the personnel have a variety of

backgrounds such as design engineering, system engineering environmental testing, and analytical and statistical techniques.

Reliability and Quality protocols for ISRO programmes have undergone continuous evolution with the objective of keeping in tune with the state-of-the-art reliability techniques. Notwithstanding this ambitious goal, the reliability activities of Indian Space Programme has its own characteristics, constraints and challenges. In this context, building up technology within the country, demands certain overall reliability codification and management directives. The significant challenge here would be to judiciously perform the balancing act of maintaining the 'heritage' of the product and at the same time to keep in pace with the emerging trends and also live within the constraints of industrial infrastructure within the country, budgets an schedules.

2. Reliability Management Practices in ISRO

For all the programmes of ISRO, from the early stages of development through final testing and deployment, measures are taken to assure the accomplishment of the required performance requirements under critical conditions. Reliability and quality issues are given utmost importance and are addressed right from the initial design stage itself. To illustrate the buildup of this process a few of the management procedures adopted are discussed.

2.1 Design Reviews: Design review is an important technique for independent evaluation of a product, providing an opportunity to the management to formally review all aspects of the design in order to ensure that the intended design satisfies the functional requirements. Design reviews are conducted on all sub systems of every programme. Such reviews are carried out at specified milestones of the programme right from the conceptual stage through the operational phase. Reviews are carefully planned and controlled. Specialists from within ISRO as well as from other premier research institutions in the country are included as members of the review teams, so that maximum use of the available talent is assured.

As a result of the design reviews, improved assurance regarding the adequacy of the design is achieved and functional groups become fully aware of the interface requirements. The exercise also authenticates the deviations observed from the approved design specifications. Above all, such scheduled examination of the system helps the management in arriving at timely decisions and assessing the cost, schedule and risk factors involved in an objective manner.

2.1.1 Conceptual Design Review: is conducted to assess the adequacy and validity of the preliminary system definition. This assures that the proposed solutions satisfy the mission requirements; that they are in line with the state of the art technology and the appropriate infrastructure available in a timely fashion.

The review is based on the results of the system level feasibility studies and the input data will include definition and analysis of mission requirements, system/cost effectiveness analysis, trade off studies and options considered identification of new

technology areas and state of the art, preliminary specifications for the major sub-systems and system interface definitions.

2.1.2 Preliminary Design Review (PDR): PDR is conducted at the end of the initial development phase and reviews the basic approach when the block diagrams and the specifications of the major elements are frozen. The PDR assures that the design approach is an acceptable solution to meet the requirement specified for the product. During the PDR the review team will consider the design studies, the evaluation of the breadboard and mock-ups and preliminary design analysis.

The inputs to PDR includes among others, functional requirements, interface specifications, technology/process specifications, conceptual design review decisions, test specifications, QA plan & system safety plans and configuration control management plan. PDR will result in approval of the system, sub-system and component specifications, identification of interface problems and solutions, basic design approach and documentation.

2.1.3 Critical Design Review (CDR): CDR is conducted when the detailed design is complete and enables the detailed performance to be evaluated, changed as necessary and frozen. The CDR establishes the baseline for production of proto types and flight units. The sub-system and components level CDR may take place as and when they are ready and this can be followed by the system level review.

The objective of the CDR is to evaluate and determine the acceptability of detailed design as depicted by technical specifications, drawings and other documentation. The CDR results in irresolution of interface problems and approval of design and freezing of documents, approval of drawings and establishment of baseline production document and finalisation of fabrication and test procedures.

2.1.4 Pre Shipment Review (PSR): PSR is conducted after successful completion of the entire series of tests prior to shipment or storage. The review is aimed at ensuring close out of all verification activities and pending operations. Its main purpose is to ascertain that all discrepancies have been properly corrected and disposed off. The review evaluates the acceptability of the system based on detailed documentation prior to shipment.

2.1.5 Mission Readiness Review (MRR): MRR will be conducted both for spacecraft and launch vehicle missions after completion of PSR to assess the readiness of the system and associated ground systems and ground stations for launch. MRR will present recommendations to Launch Authorisation Boards with specific reference to readiness of the systems and give clearance to go ahead with the launch.

2.1.6 Post Flight Analysis Review (PFA): PFA is conducted after the launch and after completion of PFA of sub-systems to assess the overall performance of the vehicle, spacecraft and mission during flight and mission. PFA will bring out a report highlighting the flight performance data observation/anomalies/analysis and

suggestions for corrective and preventive action and recommendations if any and any open issues.

2.2 Parts & Material Selection and Application: Electronic parts and materials used for space application is selected after careful study of the project requirements, availability of the parts and materials, state – of – the – art, cost and project schedules.

2.2.1 Electronic Parts: The first step in selecting electronic parts is the preparation of a Preferred Parts List (PPL). The PPL consists of a listing of the parts preferred or approved for application, consistent with the reliability and quality requirements of the project. It is the basis on which the designers select their parts. The PPL is prepared by a team of specialists including reliability, design and project engineers. The lists specify the levels of quality requirements as well as procurement specifications, manufacturer`s information, and application guidelines. Whenever a user selects a part not listed in the PPL, separate qualification procedures are established for acceptance of such non-standard parts.

To eliminate infant mortality from the part population, controlled screening and burn-in-tests are carried out on devices. Adequate de-rating factors and design guidelines are employed to minimize stress-related failures during normal operating lifetime of the subsystems. All parts are stored in a controlled environment, meeting special requirements such as grounding and anti-static provisions, where necessary. Parts thus stored are identified with batch and part codes, qualification summaries and end use.

2.2.2 Materials and Chemicals: A similar exercise is undertaken in selection and application of materials used in fabrication of subsystems, packages for space hardware. Material control is an important and essential part of ensuring quality of the system. A variety of materials and chemicals are used in any finished product and it is essential that the materials used are likely to function reliably for the designed period. It is essential that the materials and associated processes have been for use and appropriate system checks are in place to ensure quality. The processes mentioned here relate to processes which are necessary for the materials to be used as individual items of hardware and can be considered\as a part of the material processing for hardware\ realization. Examples of such processes are welding, machining operations, plating to prevent corrosion, anodizing, heat treatment etc.

Selection of given material for a specific application shall consider the heritage of materials used earlier for identical applications, use of such materials where evaluation/qualification has been previously carried out and adequate margins have been demonstrated. It shall be ensured that the materials meet the functional requirements are met and margins demonstrated, environmental conditions and application stresses have been assessed and material is capable of withstanding the temperature extremes expected during the mission life.

When new materials and processes become necessary a plan for evaluation and qualification shall be prepared and testing carried out to verify material characteristics and the ability of the material to meet application requirements. The validation of the use of new material may be made either by qualification testing of the end product subsequent to material qualification or by inspection and analysis.

A Preferred Material List (PML) provides the basis for selection of materials. A record of parts and materials used in subsystems along with all the relevant details is maintained to aid traceability of parts/materials used in case of failure or malfunction during later stages of operation.

2.2.3 Incoming Inspection Tests: To ensure repeatability of quality of parts and materials from lot to lot incoming inspection is carried out. The incoming inspection is generally carried out on all samples and percent defectives allowed in a lot is defined after careful consideration of various factors. If the failed samples exceed the percent defectives allowed the entire lot of parts or material pertaining to that batch will be rejected based on detailed examination of the test results and the heritage of the vendor.

An elaborate methodology for screening and incoming inspection of parts and materials to be used is drawn up during the initial stages of the project. The severity of screening depends upon the heritage, technology, cost and schedule. QA personnel are actively involved in these efforts of ensuring quality of parts and materials.

2.2.4 Bonded Stores: An exclusively identified area for parts and materials during storage and handling prior to fabrication and storage of sub-systems after test and evaluation is established. It is mandatory that strict environmental condition is maintained round the clock and is recorded daily. A QA plan describing the temperature, humidity, light intensity, cleanliness and antistatic measures for protection against Electro Static Discharge (ESD) damages is prepared.

Bonded Stores shall store electronic parts, materials, chemicals intended for onboard use. Reference documents received along with the components and materials, test reports shall also be available in the bonded stores. Requisition and issue details of parts and materials shall be strictly maintained. The bonded stores shall be operated and maintained by authorized and trained personnel.

2.3 Inspection and Quality Control: Inspection and Quality Control (QC) functions are introduced into the programmes right from the receipt of raw materials through fabrication and acceptance of electrical/mechanical assemblies and subsystems. QC management at ISRO comprises both surveillance functions by the R & QA groups and the individual QC cells attached to fabrication groups, subcontractors, and the project management groups. Engineering drawings, inspection checklists and acceptance criteria documents are prepared and distributed appropriately to effect adequate inspections at each point.

External vendors for supply of materials and fabrication are identified after due evaluation and review of their expertise and availability of their capability and infrastructure. External vendors thus selected have to undergo facility audit and certification, training and certification of personnel and approval of Process Identification Document (PID) for the applicable processes and materials.

Fabrication as well as inspection and storage of flight articles are carried out in areas of controlled environment conforming to cleanliness and other environmental requirements. Critical electronic packages and control components, for example, are handled only in clean rooms by trained personnel under strict supervision.

2.4 Test and Evaluation: Test and evaluation is an essential part of any engineering development programme. If the developmental risks are high, the test programme becomes the major component of the overall developmental effort, in terms of time and resources.

The primary objectives of Test and Evaluation programme are given below:

- Functional Testing – to confirm that the design meets or exceeds the basic performance requirements.
- Environmental Testing – to ensure that the design is capable of operating under the expected range of environments.
- Environmental Stress Screening to remove workmanship and process induced defects.
- Reliability Testing – to demonstrate the reliable operation of some specific elements as applicable.
- Life Testing – to demonstrate that the wear out mechanism does not affect functionality during mission life period.
- To generate adequate test/calibration data base for subsequent use in actual mission operations.

During the initial development phase, evaluation tests are carried out on the breadboard and engineering models. While records of test procedures and results are maintained, the formality is low at this stage. Qualification testing is carried out on prototype assemblies to obtain adequate assurance concerning the ability of the hardware to meet subsequent acceptance tests as well as the mission requirements. This phase is, in fact, the formal proving of the design against deficiencies, and corrective design action is taken whenever necessary. At this stage, over testing (testing beyond the specification requirements) is frequently done to determine the performance margins. In effect, emphasis is placed upon searching for design deficiencies. Flight tests are also carried out on certain specific hardware to evaluate 'in-situ' the system responses. Acceptance tests are performed on the flight articles to determine that they would survive the flight environment meeting the performance requirements. These tests also ensure that the equipment is free from workmanship defects.

Apart from the above testing operations, the test and evaluation programme includes establishing appropriate test specifications and procedures, qualification and acceptance criteria and processing and review of results. Test Review Boards are constituted to certify the validity and successful completion of equipment qualification as evidenced by the results.

2.5 Failure Analysis and Corrective Action Procedures: Formalised failure reporting and analysis procedures exist in ISRO for identifying causes of failure of components and systems encountered during the development phases. A failure, in this context, is defined as any defect or mal-function, which prevents successful accomplishment of a desired performance. Individual failures during the stages of development, such as device screening, fabrication, inspection, test and evaluation are reported to a Failure Analysis Board (FAB) whose members represent R&QA, design and chaired by a reliability engineer. The history of the failures is reviewed and the causes of failures, such as design deficiency, workmanship, test methods and the like, are determined by the Board. After analysis, specific action items are assigned to the concerned individuals for corrective action. The findings of the FAB are documented in a Failure Analysis Report (FAR), which is distributed to cognizant agencies. Failure summary reports are also brought out describing the cumulative failure experience during a specific developmental programme to enable analysis of trends and failure history.

To assist the study of failure mechanisms and modes, failure analysis laboratories are operated by the R & QA groups. These laboratories possess analytic equipment such as scanning electron microscope, radiographic instruments, stereo-microscopes, and a variety of special probes and handling systems.

2.6 Reliability Analysis: Basic statistical and analytical concepts are used to determine the degree of confidence with which the system design can be anticipated to achieve the mission goals. The first task in reliability analysis is reliability apportionment, the allocation of reliability goals to each of the several subsystems involved. In fixing these activities, important factors such as mission requirements, constraints traceable to design, fabrication, state-of-art, power, weight and cost penalties are taken into account. Following the apportionment of reliability levels, reliability prediction is undertaken. Such a prediction enables checking of the adequacy of the systems design against the apportioned reliability figures. Apart from the numerical estimates of the reliability, the analyses bring out a number of other features. For example, the reliability block diagram shows the functions of each of the subsystems, thus developing a clear understanding of the various coordinate functions among different blocks of the system. All primary failure modes are identified and described along with the effect of each on system performance. Provisions needed to prevent progressive failures (viz. Failures which, in turn, cause other failures) and redundancy requirements are highlighted.

To achieve the full potential of the reliability analysis, it has to be performed at the early phases of the development programme. The efforts have enabled identification of components/subsystems contributing significantly towards system unreliability.

Depending upon the importance and critically, it has been possible to take corrective measures to reduce the probability of failures.

Failure Mode Effects and Criticality Analysis (FMECA), which examine the quality of the system from the component, level and employ bottom-up approach, that results in identification of single point failure items are also practiced. Similarly, Fault Tree Analysis (FTA) which is a top down approach ensures meeting the reliability goals through identification of failure modes within the system is also carried out. FTA focuses on one particular undesired event at a time and determines all possible causes of that event.

2.7 Configuration Management and Control: Configuration management and control are essential part of any high reliability programme. An effective configuration control mechanism ensures good traceability, aids documentation production and guards against recurrence of mistakes. The implementation of configuration control mechanism depends on the size and nature of the project and has to be tailor made based on specific programme.

A configuration established at a particular point of time usually at inception is called a baseline. The baseline documents include drawings, specifications, test procedures, standards or any other information which defines the physical and functional characteristics. The process of managing design change from time to time involves technical evaluation, costing, finalisation of all the activities to effect the change. As the decisions may affect many functions a Configuration Control Board is set up to review all proposed changes. The board may have representatives from engineering, quality control, field engineering, customers, purchase etc. Usually the chairman of the boards has the authority to make a decision on the change while the quality representative may often be in a position of justifying the importance of change to overcome the cost and schedule disadvantages that are often present.

2.8 Non Conformance Control: Non Conformance (NC) control is a closed loop system for the management of situations arising when the product does not function to its specifications during manufacturing, assembly, test field use etc. The system will provide for identification and segregation of items which do not conform to engineering data or contractual requirements. Any departure from predefined specification is referred to as Deviation.

The definition of non-conformance depends upon the item in question. A non conforming material, product unit etc., is the one which exhibits deviation in one or more characteristics form those defined in the applicable documents like design, material, process, manufacturing, operation etc. A non-conforming system is the one, which does not meet the final performance or interface requirements as drafted in the contractual agreement. Non-conformance could further be classified as minor or major non-conformances.

2.8.1 Minor Con-conformance: is a non-conformance which does not significantly affect performance, reliability, inter changeability, safety etc.

2.8.2 Major Non-conformance: is a non-conformance, which cannot be eliminated by rework or reduced to a minor non-conformance by repair.

2.8.3 Waiver: It is an authorization to accept an item, which exhibits a major non-conformance. This is the management's decision, which overrides all the established controls and procedures. A waiver is given in an exigent situation driven by factors like degrees of criticality of non-conformance, project schedule, economies of affecting the change to circumvent the non-conformance etc.

2.8.4 Handling and disposition of non-conformance: Non-conformance is generally handled through review boards by bringing in the collective expertise of the personnel working in the respective field. Normally, it is done at three levels.

At the lowest level, it is disposed off by a preliminary review conducted by the manufacturing, assembly and QA personnel. This is done in simple and straight forward cases which either involves a minor rework or the only other option is to scrap or return to supplier.

In the middle level, Material Review Board (MRB) is constituted to review and provide disposition to non-conformances observed which could not be handled by the preliminary review. It consists of representatives from design, manufacturing, quality control etc. It provides for remedial and preventive action for non-conformances which do not adversely affect end item quality, reliability, safety, inter changeability, performance etc.

At the highest-level major non-conformance are handled by a Failure Review Board (FRB) comprising of management representatives along with other relevant technical experts. It is generally referred to in an exigent situation wherein a decision could be taken only after a thorough analysis like, risk analysis failure analysis, field data analysis, impact analysis etc.

2.9 Waiver Methodology: As explained waiver is an authorization for using a non-conforming product and could come about in one of the several ways depending upon the nature of the on-conformance.

2.9.1 Waiver by designer: Such a waiver is a minor change in specification. It may not affect the overall performance of the product or does not alter the interfaces within in the product or outside of it. However, the change is formally incorporated in the configuration definition and formally approved by the configuration control board.

2.9.2 Waiver by user: This is an acceptance of non-conforming product by the user. For example, if a user uses the product as one assembly in his total system and the non-conformance has negligible effect on the overall system performance. The user himself usually does this assessment after considering its impact on the overall risk involved, schedule, contractual obligations, financial constraints etc.

2.9.3 Waiver by Quality Control Department: It is given when a fitness for use decision is to be taken on non-critical issues. The criteria for non-criticality may be based on prior seriousness classification of characteristics. These decisions are generally found in a situation where non-conformances arise in inspection, QC tests, production tests etc., and also the deviation is either very minor or very major so that the probability of acceptance or rejection is very high, respectively.

2.9.4 Waiver by Material Review Board:

As explained earlier, the military buyers of defense products originally evolved this concept as a means of expediting decisions of non-conforming products. MRB includes members from cognizant designers and QC personnel. A unanimous decision is required with formal documentation on technical issues involved.

2.9.5 Waiver by Top Management: This is a waiver restricted to cases of a critical nature involving risks to mission and human safety, marketability, loss of revenues etc. For such cases the stakes are too high to warrant decision making from a single department or board. Hence it is taken at the highest management level.

3. Software Quality Assurance: Software Quality Assurance (SQA) is a planned and systematic activity for the evaluation of quality of and adherence to standards, processes and procedures. Processes include all activities such as designing, developing, enhancing and maintaining software; products include the software, associated data its documentation and all supporting documents.

SQA activities spread over the entire software development cycle ensures that:

- Software requirements are consistent and complete,
- Design descriptions are traceable to software requirements,
- Software design complies with standards and guidelines,
- Initialization data is consistent with reference and
- All review recommendations are implemented.

Software Quality Assurance activities are carried out inline with the SQA plan, Verification and Validation (V & V) plan and Software Configuration Management plan.

SQA plan contains the QA activities to be carried out during each stage of the software development. It identifies the responsibilities of development agency, test agency and QA teams for various activities. SQA plan also defines the review processes such as Systems Requirements Review, Algorithm Requirements, Software Requirements, Design, Implementation and so on.

V & V plan monitors technical reviews, inspections and walkthroughs. V&V activity conducts code inspection, initialization data verification, module level tests and data analysis of validation tests such as Integrated Processor Tests, On Board Computer (OBC) in Loop Simulation (OILS), Hardware Loop Simulation (HLS).

Software Configuration Management (SCM) plan provides necessary guidelines on configuration identification through a common guideline for version numbering of code and initialization data, configuration management of source code and initialization data of all onboard software components and change tracking and configuration status audits.

Thus a well-planned SQA activity assures that the software development exercise is performed strictly following the standards and guidelines set forth in the above plans.

4. Test Facilities: In order to meet the quality and reliability requirements of the space hardware, ISRO has set up a number of test facilities at its various R&D centers. A section of the important test facilities are briefly described below.

4.1 Static Test Facilities: To carry out development and qualification tests on rocket motors hardware as well as the dynamic characterization of the systems under sine and random modes.

4.2 EMI Test Facilities: Shielded chambers to test and measures interference characteristics of electronic, electrical and electromechanical systems are available. These 'RF clean' areas aid emission and susceptibility measurements on avionics packages.

4.3 Large Space Simulation Chamber: A large space simulation chamber (LSSC) is one of the few such facilities in the world has been established in ISRO, LSSC is capable of simulating space environment of hard vacuum and extreme temperatures. LSSC also has a solar simulator which generates solar spectrum using Xenon arc lamps.

4.4 Acoustic Test Facility: The high velocity gases that emanate from the rocket engines produce turbulence when mixed with the ambient air and raise the pressure fluctuations resulting in acoustic noise. To simulate such a flight environment realistically an acoustic test facility has been set up at NAL campus. This is a joint ISRO – NAL test facility.

4.5 Other Environmental Test Facilities: Thermal vacuum chambers and hot and cold soak chambers up to size of 4 m in diameter have been fabricated for component and subsystem tests. Ultra high vacuum long life test facilities aid in addition, life testing of spacecraft systems and qualification of attitude and orbit control systems. Vibration tables to simulate and test shock and vibration environment encountered by space systems have also been established.

5. Standardisation Activities in ISRO:

In a general sense standardization, as defined by the International Organisation for Standardisation (ISO), is an activity giving solution for repetitive application, to a problem essentially in the spheres of science, technology and economics, aimed at the achievement of an optimum degree of order in a given context. Generally, the

activity consists of the processes of formulating, issuing and implementing standards.

In order to meet the stringent quality and reliability demands of the Indian Space Programme a system of product assurance standards and procedures has been established in ISRO. The importance of an organized product assurance system is obvious when we consider that correction of failures is more expensive or even impossible later when they are discovered in the product realization phase.

ISRO has so far issued about 25 Product Assurance Specifications pooling the collective expertise of all centers of ISRO. These standards cover a wide gamut of activities in management, electronics, fabrication and software and are followed by all the projects of ISRO.

6. Emerging Trends and Future Perspectives: Aerospace industry today, is witnessing revolutionary trends in system realisation due to demands from the users, obsolescence of technology, rapid strides in miniaturization efforts and global competitiveness. An important impact of emerging trends on aerospace systems is technology inversion. All through, Space Programmes have demonstrated the tendency of development first and user identification later. Specifically, with the onset of fast changing trends obsolesce of technology has dictated development of space systems to incorporate new trends at a faster pace. Conventional Reliability practices have always maintained the proven approach of 'heritage' buildup, wherein, multitude of samples or models were available for the Quality engineers to carry out comprehensive Qualification programmes and then decide on the fabrication of the deliverable unit. In the wake of the demands of technology inversion, practices of concurrent engineering become imminent, so as to combine the requirements of Qualification also, into the deliverable unit. Thus, the repercussion is to streamline our model philosophy.

Space system designs have always been conservative with sufficient margins to counter variations and uncertainties. The system realization generally followed robust design techniques and the failures were attributable to randomness only. As the emerging trends in technology have brought in the complexity inversion, the established principles of maintaining relatively less complex space segment, as compared to the ground support systems, is gradually getting reversed. Today, the space systems are being developed with larger autonomy, fault tolerant features, and built in intelligence to handle normal as well as contingent mission operations.

Recent trends of large-scale integration have resulted in the merger of the characteristics and performance of component and sub-system. In addition, with the advances in device technology and increasing use of software embedded systems are available with versatile features and improved performance. All these developments dictate new philosophy of test and evaluation of not only the components but also the sub-system and systems.

7. Conclusions: The challenges of implementing quality management programmes in the Indian context are unique. Space research involves development and fabrication of systems requiring a high degree of sophisticated technology. ISRO has ambitious plans and has embarked on GSLV Mk III capable of putting 4 tonne class communication satellites in geo-synchronous orbit, exploration of lunar surface through Chandrayaan mission in the coming years. ISRO has to embark on development of new technologies and products to meet the challenges of the future. Though a mature system for quality and reliability exists with in ISRO it demands constant updating and refinement especially to meet the systems involving higher levels of integration. ISRO has also made conscious efforts to update the industries working with it on the quality practices.

Small quantities, large variety of components and stringent time schedules often make the prospective industries reluctant to cater to the needs of ISRO. It is heartening to note that of late several Indian industries both in public sector and private sector have shown keen interest and are participating in the indigenous development of high reliability electronic components and materials and development of critical technology items, which is expected to mitigate these problems considerably. Systematic approach to reviews, quality control and testing methods practiced for space systems can be easily adopted for other commercial product development also resulting in excellence in quality.

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