Surveyor Spacecraft Total Reliability Program

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A SPACECRAFT TOTAL RELIABILITY PROGRAM

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SUMMARY

The subject spacecraft total reliability program is based upon a time-phase sequence scheduled to insure that "Hi-Reliability" requirements of soft lander spacecraft can be practically applied. Such phasing allows for management planning to be responsive to required customer specifications or customizing of existing programming for customer approval. The phases to be discussed are:

Phase I Proposal and preliminary reliability design
Phase II Detailed reliability design
Phase III Fabrication, test and operation
Phase IV Postlaunch analysis
INTRODUCTION

Reliability program management to be effective requires the equivalent detailed management attention that is applied to Systems Engineering, Operations and Hardware Development. To provide such detailed attention requires a definite time-phased sequencing of events which interlock the reliability aspects into the total system program. For spacecraft (unmanned or manned and especially those required to survive surface impact, i.e., soft lander, and requiring extended space mission objectives), this means that the reliability objectives are necessarily high and the controls and disciplines applied to maintain high reliability very exacting. Experience in such environments indicates that while many tradeoffs may exist, they are normally expected program perturbations and will cause only minor changes in a program plan that is based on fundamental principles of good planning. The intent of this paper is to consider the unusual constraints of spacecraft in terms of sequencing and provision of program planning.

The means of estimating the effect of such phasing by management is through milestones achieved in each phase and ultimately in system hardware performance in simulated and actual mission operation. Postlaunch analysis and failure review techniques are primary feedback circuits for next launch corrective action and may represent a significant effort if major problems appear.
CONCEPT

Hi-reliability spacecraft objectives are closely bound to the successful completion of mission objectives which may include many severe and demanding constraints such as:

- Deep space environment
- Extremely high and low temperatures
- Radiation
- Meteorite collision
- Precision guidance tolerances
- Long mission times
- Multiple space-physics and scientific support experiments
- Soft landing on unknown surface terrains
- Manned capsules
- Minimum weight
- Launch time restraints (windows)

among many other scientific and engineering support functions.

Each of the above technical requirements plus customer schedules must be fully weighted in defining a total reliability program compatible with the system definition utilizing latest state of the art technologies.

Since total mission success of a system is desired, the basic concept developed was that any reliability effort should be systems oriented from start to finish. As a result, a total program consisting of four phases based on this concept was developed.
The first phase is initiated upon the receipt of the Request for Quotations (RFQ). This phase includes attendance at the bidders conference, technical reviews of referenced and required supporting specifications, etc., plus the formulation of various spacecraft systems, configurations and operational criteria to accomplish the mission. During this time the primary reliability tasks include:

- Developing initial system reliability block diagrams
- Determining initial reliability apportionment
- Formulating initial math model
- Establishing initial redundancy tradeoff studies
- Establishing level of materials and parts reliability and quality requirements
- Participating in vendor review teams and preparing subcontractor reliability requirements, specifications and tasks for statement of work inclusion - especially defined time required deliverables.
- Participating in system conceptual design reviews. Including component and materials consultants where new and different space environments may be suspected to have an effect upon existing systems.
- Based upon initial systems definition, parts count estimate, and preliminary reliability studies, formulating an initial A Priori Reliability prediction.

Up to this point, the primary inputs to Reliability are estimates based upon experience in other programs, standard known and published failure data, potential "state of the art" improvements as a result of research done by the company, the industry, and governmental agencies. This first approximation of system capability to meet the reliability objectives will also provide a guide as to where the quality assurance program's major effort should be directed to protect inherent reliability. Considerable flexibility is required during this phase to utilize and optimize all data inputs, which are normally quite meager and lacking necessary controls for suitable reliability consideration. As the information starts to increase, measurement of reliability growth becomes possible and the second phase of programming and definition is reached.
PHASE II

DETAILED RELIABILITY DESIGN

Phase II of this type of program effort overlaps Phase I and may parallel many of the tasks for a period of time. It is during this time span, however, when first circuit and subsystem designs are developed, reviewed and the physical detailing of the reliability model is accomplished.

This includes:

- Developing a detailed reliability program plan for customer approval
- Refining the reliability model based upon design reviews and early engineering information
- Developing the subsystem and unit math models and reliability apportionments
- Defining reliability apportionments in formal released reliability system specifications
- Establishing the necessary requirements and constraints for space usage qualification of hi-reliability components, materials and processes
- Implementing verification and traceability of parts
- Qualification testing
- In-process sampling
- Failure review activation and formal failure reporting; initiating analysis and corrective action
- Design review initiation by means of failure mode analysis and participation as a formal member of all design review committees
- Initiating subcontractor reliability surveillance
  - Subcontractor reliability requirements are detailed in the statement of work and subcontractor reliability specifications
  - Surveys in depth are made to acquaint the subcontractor with the requirements of spacecraft such as:
    - Reliability program plan
    - Reliability prediction
    - Growth curves
• Failure reporting
• Failure analysis
• Failure mode audit
• Periodic status reporting
• Coordination meetings
• Motivation training

This program is initiated at subcontractors during this phase, and continues commensurate to degree of response. The training program should stress a basic understanding of the particular spacecraft requirements, via visual aids such as slides, charts, films, etc., related to the subcontractor products.

Phase II is a critical time sequence ensuring from a reliability management aspect that essential tasks and standards are being integrated into all of the required program elements. It is at this time that a critical analysis of all reliability operations in being are scheduled, to ensure that each is clearly defined to avoid ambiguities and assume desired results. It is also in this phase that initial system prediction commence, and are continually upgraded via test data and failure analysis as available from engineering models, prototypes and subcontractors reports. Due to the nature of such data on early developmental hardware, system design, etc., large dependence must be placed upon failure mode analysis, A Priori estimates and historical information to supplement the above test data. It is in Phase III where the transformation to hard engineering data and tests results on delivered flight hardware and systems test results begin to provide reliability growth information and allow confidence limits to be placed on predictions supplied to management and the customer.
PHASE III

SPACECRAFT FABRICATION, TEST AND OPERATIONS

In this phase of the program, engineering data begins to become available from breadboard, prototype and type approval tests being evaluated under simulated launch and space environments. Type approval testing of the initial subsystem, system, prototype spacecraft, as well as various related system models - structural, thermal control and propulsion - will be providing time, cycle, performance and failure data. The subcontractors' qualification programs are in process and reliability growth information as a result of test conditions becomes available for management information. Here, therefore, the program includes:

- Based upon test results, refined failure mode analysis, and failure reporting, reliability predictions and math model are refined.
- Failure review board follows closely failure reports, diagnosis and originates corrective action requests.
- Failure mode audits are updated and completed.
- Close management surveillance to subcontractors is provided, and ensures that each is producing contractual outputs.
- Reliability assurance test programs on flight assured hardware are developed. These programs are based upon an "Equivalent Mission Cycle" (EMC) concept and require rigorous data review of all program testing as well as a commitment of basic flight hardware for unit and subsystem mission simulation evaluation. Senior reliability personnel are designated as "Test Directors" and initiate planning, scheduling and reliability test operations.
- Subcontractor reliability program milestones are reviewed. Submittals such as failure mode audits, monthly predictions, growth curves and data submittals are analyzed and on-site surveillance trips are increased.
- Reliability training and motivation programs are prepared and presented to prime and subcontractor personnel at key hardware delivery milestones, to maintain personnel awareness of the role each plays in their product reliability.
- As spacecraft systems become available for testing, system test teams are activated and reliability test team representatives are assigned from initial test to field launch site to ensure that all test data include timing and cycle information, that adequate information is supplied on failure reports, and that corrective actions on system problems, test equipment and procedures are initiated and followed-up. Adequacy of subsystem and unit data packages through a reliability unit history log is also a prime responsibility.
The effect of all unit and system specification and engineering changes are reviewed and approved by Reliability as are all specifications and procedures initially released.

Reliability launch critiques are prepared during this phase for day by day updating by the test team reliability member. This includes status of all units with respect to end of life, changes in characteristics or performance, on-off cycle wear and system tradeoff where system redundancies are involved. Of particular significance would be parameter drift indications during final "Operational Readiness" testing.

Finally, as each spacecraft system is assembled, tested, shipped and mated to its launch vehicle, a continuously updated reliability prediction for spacecraft performance to its design specification is maintained and provided to management for launch visibility.

Phase III is the hardware and launch oriented portion of these programs and extends from source surveillance to launch operations. It uses a priori estimates, available test data, failure mode analysis, failure reporting, systems test data feedback, special reliability test programming, machine techniques and analysis to achieve continuously updated reliability data and prelaunch predictions. This will continue to overlap Phase IV until last program launch when only postlaunch analysis and final reporting will be major milestones.
PHASE IV
POSTLAUNCH ANALYSIS

Reliability effort provides one of the strongest inputs to postlaunch analysis. The responsibility for failure review, system data package, system test failure reporting and launch operations data action accountability lie within the normal scope of work. Working in consonance with the Mission Analysis team, the reliability organization has a responsibility to provide a number of detailed and specific inputs to the program and to launch and program reporting.

These include:

- Support of the postlaunch data analysis team is provided via review and analysis of prelaunch, launch and operations data and problem summaries.

- As a result of analysis, corrective action for next launch is initiated to update requirements and spacecraft hardware or procedures.

- Management is provided with postflight reliability summaries and recommendations for next flight action.

- Based upon previous postlaunch analysis and corrective actions, the next launch reliability critique and prediction is refined, communicated to management, and incorporated in the launch director's reliability critique manual.

- Upon program launch completion, a summary reliability report is prepared briefly describing program achievements and providing a full accountability of system, unit and component performance and potential solutions to next generation problems.
PROGRAM ORGANIZATION

Each spacecraft reliability office is uniquely associated line-management wise with its Project Management Office. Reliability is considered a system function associated via System Engineering to Project Management and hence Division Management. In the same way, therefore, that System Engineering defines and controls system performance, Reliability defines and controls system reliability. Following are some of the reliability oriented controls that are specifically for space applications:

- Space qualified materials
- Space qualified preferred parts
- Space qualified processes
- Cradle to grave parts accountability
- Variation and substitution authorization cognizance
- Approval of all specifications and procedures
- Approval of all specification and procedure changes
- Subcontractor reliability program control
- Chair failure review boards
- Failure reporting and failed parts collection
- Equipment reliability history log
- Reliability representatives on all system test teams
- Reliability assurance test program direction
- Postlaunch analysis team representatives

In each of these facets, the reliability team supports Project Management in making appropriate decisions concerning spacecraft COST, SCHEDULES, PERFORMANCE and RELIABILITY. By including Reliability in fourth place, due consideration is being given to the risk decision that Project Management must make concerning the four major elements. Where Reliability may be only a minor factor, certain decisions may be made with respect to a launch of an unmanned spacecraft that would have a different connotation for a manned launch, i.e., one of the number of scientific instruments inoperative might not hold up an unmanned launch, but any system primary or secondary being inoperative would hold a manned launch.
CONCLUSION

The discussed four-phased program provides the necessary ingredients to satisfy most program requirements and, while accepting customer requirements, will retain the individual characteristics of any space oriented organization. Each contracting organization will have its own specifications and programs which must be adhered to, but each contractor must still retain the individualism of organizational integrity and management structure that allows for economical and timely execution of contractual commitments. Such phasing provides clear identifiable program benchmarks and allows project management visibility into problems and progress.