Technique	Programmatic provisions for ease of maintenance greatly enhance hardware and software system operational effectiveness for both in-space and ground support systems.

BENEFITS OF IMPLEMENTING MAINTAINABILITY ON NASA PROGRAMS

***Include the principles of maintainability early in the development process to realize significant benefits in all program life cycle phases*.**

Benefits	Implementation of maintainability principles can reduce risk by increasing operational availability and reducing lifecycle costs. Provisions for system maintainability also yields long term benefits that include decreased maintenance times, less wear and tear on project personnel, and extended useful life of ground and in-space assets.
Key Words	System maintainability, program management, lifecycle costs, availability, concept development, human factors
Application Experience	International Space Station Program, Hubble Space Telescope, SRB's, Shuttle GSE, Space Acceleration Measurement System, and others.
Technical Rationale	Maintainability requirements for programs that require ground and/or in-space maintenance and anomaly resolution have to be established early in the program to be cost effective. Lack of management support to properly fund maintainability activities up-front can result in increased program risk. Including maintainability in the design process will greatly reduce the number of operational problems associated with system maintenance, improve the availability of the system, and reduce program costs.
Contact Center	**All NASA Field Installations**

Benefits of Implementing Maintainability on NASA Programs
Technique PM-1

Over the years, NASA has successfully launched manned spacecraft to the moon, sent unmanned probes into the outer reaches of the solar system, and developed reusable space systems for earth orbitable missions. NASA also performs valuable atmospheric research and development of ground systems, all of which contain complex hardware and software that must be maintained during all phases of operations and in multiple environments. However, in this age of shrinking budgets, doing more with less is becoming the overall programmatic theme. NASA space flight programs are being driven towards more automated, compact designs in which fewer support resources will be available than in past programs. This technique will outline the benefits of implementing well-defined and user-friendly principles of maintainability on all NASA programs, regardless of the operational scenario. Emphasis is placed on how and why a maintainability program can enhance the effectiveness of a system and its overall operation. It must be noted, however, that maintainability of unmanned deep space systems provides a different set of challenges.

Maintainability is defined in NASA Handbook 5300.4(1E), "Maintainability Program Requirements for Space Systems," as: "A measure of the ease and rapidity with which a system or equipment can be restored to operational status following a failure," and is consistent with NHB 7120.5, "Management of Major Systems and Projects." It is a characteristic of equipment and installation, personnel availability in the required skill levels, adequacy of maintenance procedures and test equipment, and the physical environment under which maintenance is performed. Applying maintainability principles will enhance the systems readiness/availability through factors such as visibility, accessibility, testability, simplicity, and interchangeability of the systems being maintained. Using maintainability prediction techniques and other quantitative maintainability analyses can greatly enhance the confidence in operational capabilities of a design. These predictions can also aid in design decisions and trade studies where several design options are being considered. Also, cost savings and fewer schedule impacts in the operational phase of the program will result due to decreased maintenance time, minimization of support equipment, and increased system availability. Another benefit is a decrease in management overhead later on in the life cycle as a result of including maintainability planning as a full partner in early maintenance/logistics concept planning and development.

PROGRAMMATIC BENEFITS

Maintainability Program Implementation

Project management is responsible for implementing maintainability on a program via development of specific requirements for cost effective system maintenance in the early phases of the life cycle. Trade studies of the impacts of maintainability design on life cycle costs are used to evaluate the balance between cost of designing to minimize maintenance times and the associated increase in system availability resulting from the decrease in maintenance times. Usually, the up-front cost of designing-in maintainability is much less than the cost savings realized over the operational portion of the life cycle.

Several programs have opted to accept the short-term cost savings by deleting maintainability requirements in the design phase, but the associated increase in maintenance and support costs incurred during operations would have been significant. An example of this is the Space Station Program, which had deleted requirements for on-orbit automated fault detection, isolation and recovery (FDIR), saving the program up-front money. However, the alternative concept was to increase the mission control center manpower during operations for ground based FDIR, but this presented a significant cost increase when averaged over the life cycle. Another positive example is the Hubble Space Telescope Program. Maintainability concepts were included early in the life cycle, where maintenance planning and optimum ORU usage in design saved the program significant costs when on-orbit repairs became necessary. Figure 1 accentuates the cost tradeoffs between introducing maintainability concepts into a program and the time at which they are introduced. These tradeoffs can mean the difference between a successful maintainability program and a costly, less effective one.

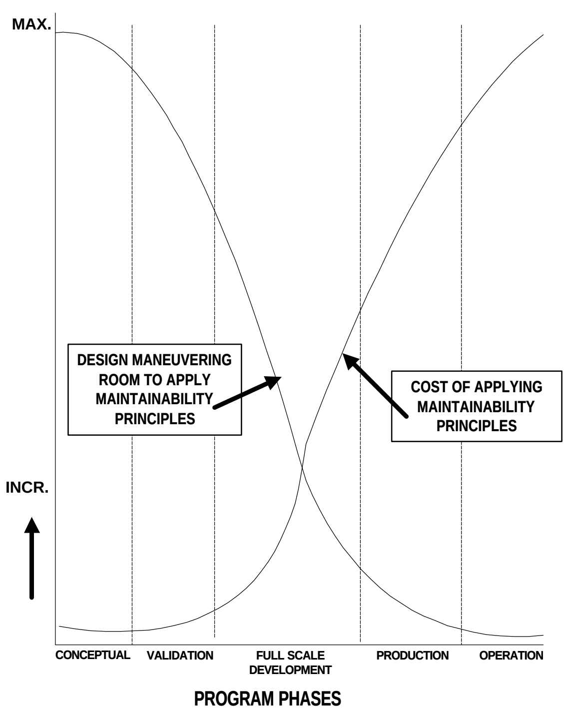

Figure 1. Effect of Implementing Maintainability Program vs Phase

The NASA systems engineering process should require that the system be designed for ease of maintenance within it's specified operating environment(s), and should ensure that the proper personnel (design and operations maintainability experts) and funds are committed to development of the process to achieve maximum program benefit. Program schedule will be affected by lack of system maintainability because necessary ground support will increase, maintenance times will be higher, necessary maintenance actions will increase, EVA will be at a premium, and system availability will be lower. Table 1 highlights key program benefits.

Table 1: Maintainability Programmatic Benefits

- Enhanced System Readiness/ Availability
  - Reduced Downtime
  - Supportable Systems
  - Ease of Troubleshooting and Repair
- System Growth Opportunities
  - Hardware/Software Modifications
  - Interchangeability
  - Modular Designs
  - Decreased Storage Considerations
- Reduced Maintenance Manpower
- Reduced Operational Costs
- Compatibility with other Programs
- Reduced Management Overhead

Maintenance/Logistics Concept Development

Development of the maintenance and logistics concepts for a program early in the life cycle must include the maintainability characteristics of the design. The maintenance concept is a plan for maintenance and support of end-items on a program once it is operational. It provides the basis for design of the operational support system and also defines the logistics support program, which will determine the application of spares and tools necessary for maintenance. The use of other logistic resources, such as tools and test equipment, facilities and spare parts, will be optimized through including maintainability planning as a key operational element. Derivation of these plans early on in the life cycle solidifies many operational aspects of the program, thus allowing for integrated design and support planning development.

MAINTAINABILITY DESIGN BENEFITS

Visibility

Visibility is an element of maintainability design that provides the system maintainer visual access to a system component for maintenance action(s). Even short duration tasks such as NASA space shuttle orbiter component inspection can increase downtime if the component is blocked from view. Designing for visibility greatly reduces maintenance times.

Accessibility

Accessibility is the ease of which an item can be accessed during maintenance and can greatly impact maintenance times if not inherent in the design, especially on systems where on-orbit maintenance will be required. When accessibility is poor, other failures are often caused by removal/ disconnection and incorrect re-installation of other items that hamper access, causing rework. Accessibility of all replaceable, maintainable items will provide key time and energy savings to the system maintainer.

Testability

Testability is a measure of the ability to detect system faults and to isolate them at the lowest replaceable component(s). The speed with which faults are diagnosed can greatly influence downtime and maintenance costs. For example, deficiencies in Space Shuttle Orbiter testability design have caused launch delays, which translate to higher program costs. As technology advances continue to increase the capability and complexity of systems, use of automatic diagnostics as a means of FDIR substantially reduces the need for highly trained maintenance personnel and can decrease maintenance costs by reducing the erroneous replacement of non-faulty equipment. FDIR systems include both internal diagnostic systems, referred to as built-in-test (BIT) or built-in-test-equipment (BITE), and external diagnostic systems, referred to as automatic test equipment (ATE), test sets or off-line test equipment used as part of a reduced ground support system, all of which will minimize down-time and cost over the operational life cycle.

Simplicity

System simplicity relates to the number of subsystems that are within the system, the number of parts in a system, and whether the parts are standard or special purpose. System simplification reduces spares investment, enhances the effectiveness of maintenance troubleshooting, and reduces the overall cost of the system while increasing the reliability. For example, the International Space Station Alpha program has simplified the design and potentially increased the on-orbit maintainability of the space station, thus avoiding many operational problems that might have flown with the Freedom Program. One example is the Command and Data Handling Subsystem, which is the data processing backbone for the space station. Formerly, the system consisted of several different central processing units, multiple level architecture, and several different network standards. The new design comprises only one network standard, one standard CPU, and a greatly reduced number of orbital replaceable units (ORU's). Maintainability design criteria were definite factors in the design changes to this space station subsystem.

Reduced training costs can also be a direct result of design simplification. Maintenance requires skilled personnel in quantities and skill levels commensurate with the complexity of the maintenance characteristics of the system. An easily maintainable system can be quickly restored to service by the skills of available maintenance personnel, thus increasing the availability of the system.

Interchangeability

Interchangeability refers to a component's ability to be replaced with a similar component without a requirement for recalibration. This flexibility in design reduces the number of maintenance procedures and consequently reduces maintenance costs. Interchangeability also allows for system growth with minimum associated costs, due to the use of standard or common end-items.

Human Factors

Human factors design requirements also should be applied to ensure proper design consideration. The human factors discipline identifies structure and equipment features that impede task performance by inhibiting or prohibiting maintainer body movement, and also identifies requirements necessary to provide an efficient workspace for maintainers. Normally, the system design must be well specified and represented in drawings or sketches before detailed anthropometric evaluation can be effective. However, early evaluation during concept development can assure early application of anthropometric considerations. Use of these evaluations results leads to improved designs largely in the areas of system provisions for equipment access, arrangement, assembly, storage, and maintenance task procedures. The benefits of the evaluation include less time to effect repairs, lower maintenance costs, improved supportability systems, and improved safety.

Summary

Implementation of maintainability features in a design can bring about operational cost savings for both manned and unmanned systems. The programmatic benefits of designing system hardware and software for ease and reduction of maintenance are numerous, and can save a program, as seen with NASA's Hubble Space Telescope. Maintenance in a hostile, micro-gravity environment is a difficult and undesirable task for humans. Minimal exposure time to this environment can be achieved by implementing maintainability features in the design. The most successful NASA programs have been those which included maintainability features in all facets of the life cycle. Remote system restoration by redundancy management and contingency planning is particularly essential to assuring mission success on projects where manned intervention is either undesireable or impractical.

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