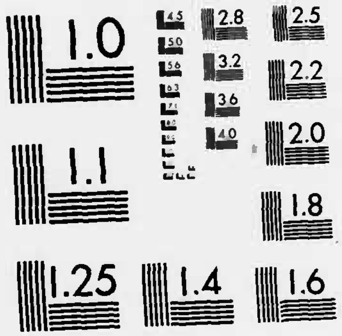
AD-A134 957 AN INVESTIGATION OF NON-EXTRAVEHICULAR ACTIVITY (NON-EVA) ON-ORBIT MAINTE..(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF SYST.. R A ABORN 1/1

UNCLASSIFIED SEP 83 AFIT-LSSR-86-83 F/G 22/2 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AN INVESTIGATION OF NON-EXTRAVEHICULAR ACTIVITY (NON-EVA) ON-ORBIT MAINTENANCE SUPPORT CONCEPTS FOR ORBITING SYSTEMS

Roni A. Aborn, Captain, USAF

LSSR 86-83

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

83 11 28 012

AN INVESTIGATION OF NON-EXTRAVEHICULAR ACTIVITY (NON-EVA) ON-ORBIT MAINTENANCE SUPPORT CONCEPTS FOR ORBITING SYSTEMS

Roni A. Aborn, Captain, USAF

LSSR 86-83

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER LSSR 86-83	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) AN INVESTIGATION OF NON-EXTRAVEHICULAR ACTIVITY (NON-EVA) ON-ORBIT MAINTENANCE SUPPORT CONCEPTS FOR ORBITING SYSTEMS		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Roni A. Aborn, Captain, USAF		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS School of Systems and Logistics Air Force Institute of Technology, WPAFB OH		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Department of Communication, AFIT/LSH WPAFB OH 45433		12. REPORT DATE September 1983 13. NUMBER OF PAGES 63
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Approved for public release: IAW AFR 190-17.

LYNN E. WOLAVER
Dean for Research and Professional Development
Air Force Institute of Technology (ATC)
Wright-Patterson AFB OH 45433

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Space Maintenance
Teleoperators
Unmanned Spacecraft
Extravehicular Activity
Design
Visiting System
Orbital Repair
Spacecraft
Maintainability

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Thesis Chairman: Rodney C. Byler, Major, USAF

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Designing highly reliable, expendable satellites for long duration, on-orbit missions is becoming increasingly impractical. Incorporating a maintainability aspect is one way of facilitating the required level of probability of mission success. A hypothetical satellite constellation, Space Fox, is discussed in identifying the "design to build" criteria, technical capabilities, and economic considerations necessary to facilitate NON-EVA on-orbit maintenance repair concepts. The acquisition cycle provides a vehicle for showing the relationship between the maintenance concept and maintenance plan, and developing a system to include NON-EVA on-orbit repair capabilities. Specific levels of concept design, technical limitations and economic trade-offs are identified. System optimization and prime equipment compatibility are addressed. NON-EVA on-orbit maintenance by a pivoting arm mechanism servicer, carried by the Teleoperator Manuevering System, is a technically and economically feasible way of supporting orbiting space assets. A recommendation to develop an implementation plan, reliability simulation and stimulate funding for further research and development of the design engineering and technical advances required is presented.

LSSR 86-83

AN INVESTIGATION OF NON-EXTRAVEHICULAR ACTIVITY (NON-EVA) ON-ORBIT MAINTENANCE SUPPORT CONCEPTS FOR ORBITING SYSTEMS

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

By

Roni A. Aborn, BA
Captain, USAF

September 1983

Approved for public release;
distribution unlimited

This thesis, written by

Captain Roni A. Aborn

has been accepted by the undersigned on behalf of the Faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN LOGISTICS MANAGEMENT

DATE: 28 September 1983

Rodney C. Byler

COMMITTEE CHAIRMAN

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Purpose

Interest in space exploration dwindled after the landing on and safe return of man from the moon. America's attention turned back to space when the first shuttle was launched on 12 April 1981. On the 4th of July 1982, a day of national celebration, President Reagan declared the space shuttle operational and announced a new National Space Policy. One of the principles outlined in the directive is: "The United States is committed to the exploration and use of space by all nations for peaceful purposes and for the benefit of mankind [13:1]."

The space shuttle affords the United States new opportunities to develop space technology, technology ranging from on-orbit repair of satellites to building an inhabitable space station. As technology advances and mission life-span requirements increase, the trade-offs between system reliability and system maintainability must be looked at more closely than ever before. Past studies are a good source for evaluating trade-offs.

The purpose of this research effort is fourfold. The first goal is to condense and summarize the materials written about space maintenance. This will provide a source for an easy overview of what studies have been accomplished in the areas of manned and unmanned on-orbit repair concepts.

The second objective is to support the non-extravehicular activity (NON-EVA) school of on-orbit repair of satellites. The major thrust thus far has been to develop the capabilities of manned repair concepts and extravehicular activity (EVA). Because of the hazardous environment in space, man's capabilities are limited and, to overcome these limitations, NON-EVA concepts must be developed. Developing these concepts takes money. The third goal of this effort is to inspire additional funding of research and development in areas applicable to NON-EVA maintenance concepts, to include modularity and standardization of satellite design.

Included in the design of a satellite must be the parameters of maintainability and reliability. These parameters are also a part of the development of the maintenance concept and maintenance plan. The process of this development will be discussed further in the background section of this chapter. The importance of this development is brought out in the fourth purpose of this effort which is to show the relationship between the maintenance concept and the maintenance techniques required to facilitate NON-EVA on-orbit repair.

Background

Designing a satellite system to facilitate on-orbit repair must include very careful development of the maintenance concept. When developing the maintenance concept, the system's operational requirements must be analyzed and the repair policies necessary to support these requirements must be identified (2:113). The maintenance concept lists needs, considerations, and constraints for a new system (17:5). More specifically, it consists of a progression of postulates and/or diagrams defining criteria covering maintenance levels, major activities accomplished at each level of maintenance, basic support policies, effectiveness factors, and primary logistics support requirements (2:19-20). The maintenance concept is the basis for planning. It attempts to ". . . ensure that all functions of design and support are integrated with each other and track the same concept [2:105]."

The preliminary maintenance concept is developed in the conceptual phase of the program acquisitions cycle. It is tailored to the system operational concept (17:5). Included in the system and maintenance concepts are the integrated logistics support (ILS) elements. There are fifteen ILS elements (3:p.10-6). Air Force Regulation 66-14, Equipment Maintenance, specifically mentions seven of them in the description of maintenance concept development. The maintenance concept development procedures outlined in this regulation apply ". . . to all Air Force activities, systems and equipment, except for civil engineering, medical, vehicular, and automatic data processing equipment and components. . . [17:1]." A brief description of the seven elements specified in the regulation follows:

1. Reliability and Maintainability: Design parameters that influence performance and economics of a system.

2. Maintenance Planning: Establishes concepts and requirements for the classification of maintenance to be performed over the system life-cycle.

3. Support Equipment: Ensures the availability and performance of required equipment, e.g., maintenance, calibration, and automatic test equipment.

4. Packing, Handling, and Transportaiton: Defines the requirements, resources, and procedures essential for the proper transportation, preservation, and handling of system equipment and support items.

5. Technical Data: Provides the informational communication link needed to translate requirements language into usable information for developing, producing, supporting, operating, and maintaining a system in a readiness configuration.

6. Computer Resources Support: Ensures that facilities, hardware, software, and manpower requirements in this area are planned and programmed to be available when necessary.

7. Survivability: Vital to mission accomplishment; preservation planning of the survivability design features throughout the systems life-cycle (3:pp.10-7 to 10-9). These elements define the preliminary maintenance requirements for a system.

With the preliminary maintenance requirements defined, the maintenance concept is specific enough to direct logistics aspects, yet flexible enough to permit trade-offs (17:5). These trade-offs occur as the system operational concept develops and hard data becomes available through functional analysis. Functional analysis is a bridge between the conceptual and the demonstration and validation phases of the acquisition process. Basically, it involves comparing the system operational requirements and the actual technical capabilities, realizing and analyzing the differences to come up with a functional description on the system, to include determining the maintenance requirements, (an update to the maintenance concept), to ensure that the system can be effectively and economically supported during its life-cycle. The objective of functional analysis is to attain the appropriate balance between the factors of performance, effectiveness, support, and economics (2:117-118).

Once the operational functions, maintenance requirements, and design criteria are defined, the maintenance concept becomes an input to the logistic support analysis (LSA) process. LSA is an iterative process that begins during the demonstration and validation phase of the acquisition cycle (17:6). It forces early consideration and maximum consistency between the prime equipment and its related logistics support through an iterative process of analysis (2:138).

By integrating and applying various analytical techniques, LSA serves as a tool in accomplishing trade-off studies between the maintenance concept and the proposed system design (17:6). The ILS requirements are updated through the LSA process, beginning with gross estimates and being refined as firm data and design models are available (2:143). The processes of the iterative approach are depicted in Figure 1 (2:141).

An output of LSA, evolving from the input of the maintenance concept, is the maintenance plan (2:19-20). This transition occurs during the full-scale engineering development phase of the acquisition cycle (17:7). The maintenance plan is a formal document specifying how the maintenance concept is to be implemented. It contains details specifying methods, resources, and procedures for system support that will be followed during the consumer use phase of system life-cycle (2:19-20). The maintenance plan is revised iteratively to ensure technical requirements are met during full-scale development (17:7).

The maintenance plan is evaluated again in the production and deployment phases to see how well the requirements have been met, and to do any final trade-offs between

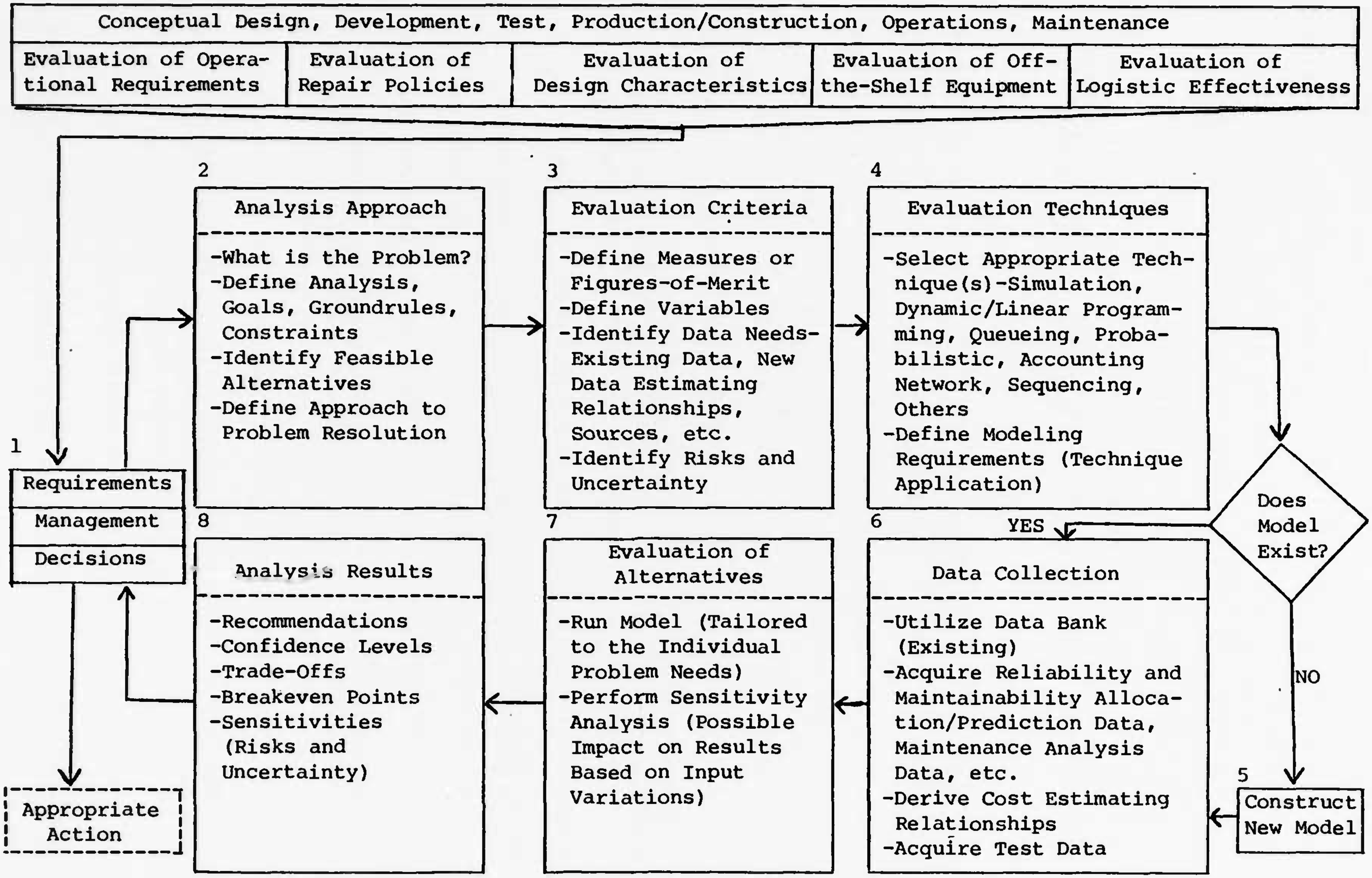


Fig. 1. Logistic Support Analysis Approach (2:141)

design and support (17:7). The maintenance plan is monitored throughout the system life-cycle, and further changes are made for experience and changing operational concepts (17:8). Further clarification of this process will be discussed in Chapter IV as specific criteria are defined in developing the maintenance concept and plan applicable to NON-EVA on-orbit repair.

The present maintenance concept for on-orbit systems is primarily to build highly reliable systems with redundancy instead of maintainability factors built-in. These systems are expendable; and once their mission life span is over, they are forgotten. Now that the shuttle has successfully retrieved a satellite, future systems will include a ground-refurbishment support system and concept.

System support is more often called maintenance. "Maintenance includes all actions necessary for retaining a system or product in, or restoring it to, a serviceable condition [2:19]." Unscheduled actions taken to restore a system after a failure are categorized as corrective maintenance. Actions that are scheduled, including inspection and servicing, are considered preventative maintenance and serve to retain the system at a specific performance level (2:35).

Maintenance can also be classified according to where the action takes place. Tasks performed at the operational site on fully assembled systems ready for use is on-equipment maintenance. Off-equipment maintenance consists of actions performed on components removed from the system and processed through repair shops (17:13).

A further break-out of maintenance classification is levels of maintenance. Historically, three levels of maintenance have been defined as: organizational, intermediate, and depot. Organizational maintenance requires the least specialized technical skills; is performed at the prime equipment site; and is limited to tasks such as visual inspections, operational check-outs and external adjustments. Intermediate maintenance requires a higher degree and specialization of technical skills; is performed in mobile, semi-mobile, or fixed repair facilities; and generally includes activities like major equipment repair, complicated adjustments, and detailed inspection and system check-out (2:109).

Depot maintenance involves overhauling, rebuilding, modifying, and retrofitting of systems and/or equipment. Special facilities are required, and a high level of technical skills is necessary (2:109). Not all systems incorporate the three level break-out. The point here is, for each system, the appropriate level(s) must be defined early in the development of the system to facilitate effective system support requirements and ensure mission performance success throughout the system life-cycle.

Justification for Study

To facilitate maintenance of an orbiting system, new concepts and techniques must be addressed now. In order to prevent "reinventing the wheel," a consolidation of the research already accomplished is very important. In addition, the organizational and procedural infrastructure and architecture necessary to develop maintenance support for space assets needs to be more clearly defined. This is especially true in maintaining and/or creating an understanding of the relationship between the maintenance concept and maintenance plan, and the development of a satellite NON-EVA maintenance techniques.

This understanding is essential in establishing a greater acceptance of NON-EVA on-orbit repair capabilities. As well as raising the level of acceptance, a stronger effort must be made in the area of acquiring the necessary funds to continue and/or restart the research efforts in the area of NON-EVA techniques.

Problem Statement

The decision as to whether a system's "design to build" criteria will incorporate a NON-EVA maintenance requirement must be based on the technological and economic factors that are in control during the development, test and evaluation stage of each new system. The capabilities of the shuttle have initiated new ideas towards the ability to perform on-orbit maintenance. As the shuttle's capabilities increase and with further advances in and verification of existing technology, can NON-EVA on-orbit maintenance of satellites be an effective and efficient way to support our space assets?

Research Objective

In the near future (five to ten years), the capability to perform on-orbit maintenance will be a reality. Therefore, the decision as to which, if any, components/ systems will have this type of maintenance performed requires a critical analysis of what is possible, both in the design criteria and in space. The overall objective of this research is to show that NON-EVA on-orbit repair is technically and economically feasible and an effective and efficient method of supporting orbiting space systems.

Research Questions

To demonstrate this feasibility, the following questions must be researched; and valid, supportable answers presented.

1. What technical capabilities are required to facilitate spacecraft NON-EVA on-orbit repair?

2. What spacecraft "design to build" criteria are required to facilitate NON-EVA on-orbit repair?

3. What economic factors must be considered in opting for spacecraft NON-EVA on-orbit repair?

Scope and Limitations

In order to systematically research the capabilities, criteria, and considerations set forth by the research questions, the creation of a postulated orbiting system was required. This system is a satellite constellation which will be referred to as Space Fox. Space Fox has the following characteristics:

1. An operational requirement for an earth coverage communications network.

2. A total of eighteen satellites.

3. A twenty- to thirty-year on-orbit mission life span.

4. A medium earth orbit of between 1,200 and 1,400 miles.

5. Three equally spaced orbits, six satellites per orbit.

6. Orbits separated by 120 degrees in right ascension and inclined at 74 degrees.

Available, unclassified literature in the area of space maintenance research was the only type of material selected. Much of the research is of an extremely technical manner, and it is not the intent of this effort to arrive at a technical or parameter defining mathematical model to affect statistical results. Therefore, those data were omitted.

Methodology

To obtain the material in the area of space maintenance, Defense Technical Information Center (DTIC) (a distributing function) Defense Logistics Agency, Cameron Station, Alexandria, Virginia 22314, bibliography search was initiated using the key words: space maintenance and on-orbit repair. The bibliography was then reviewed to select entries that were most applicable and unclassified in nature. The acquired material was then synthesized and analyzed for its applicability to the purposes of this study. It was further analyzed as to its ability to provide and facilitate support of NON-EVA on-orbit maintenance concepts and meet the technical capabilities, design criteria, and economic considerations of Space Fox.

Assumptions

The feasibility of having a system like Space Fox, even if all other characteristics and criteria are met, must lie in the assumption that the existing treaties concerning the nonaggressive operations in space will be followed.

Summary and Preview

This chapter has provided a basic foundation of the fourfold purpose of this effort. A background of system maintenance concept development and its importance is included. Study justification and the problem to be addressed are stated and lead to the research objective and questions. Space Fox's characteristics and research scope, limitations, and assumptions are set forth. This effort will continue with a literature review of the research reports, in an abbreviated, abstract form. Chapter III presents the methodology used to analyze the data in these reports to meet the constellation criteria. Chapter IV discusses the results and findings of this analysis in developing Space Fox. Chapter V states the conclusions reached and the recommendations for further research in the capabilities for NON-EVA on-orbit maintenance action.

CHAPTER II

LITERATURE REVIEW

Literature in the area of space maintenance is limited at best. Most of the recent articles and reports are concerned with the defense aspects of what needs to be put in space as opposed to how to maintain it once it is there. During the 1960s when landing a man on the moon was the National Space Policy, almost every theory or concept concerning living or operating in space was researched and written about. Since then, very little has been written about the advances in maintenance technology that have been made in the exploration of space. Another segment of the present information is not in written form, but in early conceptual phases in the minds and on scraps of paper of the people working in the field of developing space maintenance techniques. Some of the maintenance techniques and operations research that is ongoing at this time is of a classified nature.

Pre-1970 Studies

Even though the literature is dated, it covers on-orbit repair areas that are again in the forefront, i.e., what is possible in design technology and in space to facilitate on-orbit repair. A 1963 technical report by Bell Aerospace Corporation, for the Aeronautical Systems Division, at Wright-Patterson Air Force Base, entitled "Study of Space Maintenance Techniques," was devoted to establishing preliminary concepts for maintenance and assembly techniques for spacecraft and component repair techniques using space tools and fasteners, and remote manipulators (14). Five different systems were studied to identify operating environments and maintenance, assembly, and repair functions. Component failure rates and malfunction modes were established and maintenance requirements were identified to repair the systems. Preliminary maintenance concepts, appropriate to the space maintenance tasks, were developed.

The space environment, and the effects of this environment on maintenance, were included in the Bell Aerospace Corporation report. The hazards to a space maintenance worker and his capability to perform were also discussed. In summary, the report favors the manned versus the remote manipulator concept for accomplishing on-orbit maintenance. However, the study recognizes the importance of spacesuit and/or maintenance capsule design to allow the dexterity required to accomplish the maintenance tasks in reasonable times and acknowledges the impact of the environmental hazards on the design.

"Space Systems Maintenance Evaluation Model," a 1964 Boeing Company study, was conducted to establish quantitative relationships of maintainability parameters of an orbiting spacecraft and identify data required for comparison of design concepts (1). The parameters included mission life span, maintenance requirements for manned repair concepts, frequency of repair, and reliability.

An analysis of the Extended Apollo Laboratory Module, a part of the Apollo spacecraft system, was performed to (1) obtain design criteria, (2) define the interrelationships of the functional support activities, (3) develop a simulation model of orbital maintenance operations, and (4) use the model to obtain evaluation data. Methodology was developed to identify the activities required to conduct maintenance. The activities were analyzed to define the resources and time required for accomplishment of the task. This method formed the basis for the general simulation model.

This general simulation model is designed for use with any orbiting spacecraft and is referred to as the Space Systems Maintenance Evaluation Model. By providing correct inputs of failure criticality and component maintainability, good estimates of design and maintenance requirements can be obtained.

In a technical paper on "Maintenance in a Weightless Environment," written by Chester May in 1965, reports and studies on efforts performed by the U.S. Air Force and industry under contract with the Air Force (including the two reports described above) are discussed and summarized (12). These reports deal with four specific Air Force objectives in the area of the establishment of a capability to maintain, assemble, and repair vehicles in a space environment.

The first objective is to develop maintenance design criteria for space designers. To achieve this objective, a two-phased effort was performed by Bell Aerosystems Company. The two phases are (1) research to investigate and determine the maintenance requirements of present and future systems by selecting five typical vehicles and performing a detailed analysis of the system and subsystems of each; and (2) research to investigate the constraints placed on the orbital worker by the spacesuits, weightlessness, available tools, and phenomena such as micrometeorites and radiation.

Developing maneuvering units to translate astronauts between spaceships is the second objective. The Air Force has developed an Astronaut Maneuvering Unit (AMU), a Remote Maneuvering Unit (RMU), and a space shuttle. The AMU is a self-contained unit with its own power supply and equipment for propulsion, stabilization, and life support. The RMU is designed to be remotely controlled from a mother vehicle. The space shuttle in this study is not the Space Transportation

System (STS) shuttle that is now in operation. It is a smaller hard-shell maneuvering unit that contains its own life support, power supply, and provisions for propulsion and stabilization.

The third objective is to define the specifications for maintaining techniques, tools and attachments. The Air Force conducted tests using 5- and 6-degree-of-freedom simulators and zero-g aircraft flying the Keplerian trajectory, which is a technique of flying an aircraft to achieve zero-gravity conditions (12). This was used to develop and define the concepts, tools, and techniques to perform in-space maintenance. To meet the fourth and final objective, providing an analytical model to simulate space maintenance, the Air Force contracted Boeing for the effort. The model is referred to as the Space Systems Maintenance Evaluation Model and will be used to (1) evaluate design changes to improve maintenance procedures and policies; (2) evaluate procedures and operation to improve performance, increase efficiency, and reduce cost; (3) identify factors which can reduce downtime of the system; and (4) provide information essential to realistic maintenance planning. The results of these efforts enabled the development of techniques, equipment, and tools for space maintenance. Test data evaluations are encouraging in the prediction of a practical space maintenance capability.

The purpose of a 1966 report by Grumman Aircraft Engineering Corporation, "Extravehicular (EVA) Space Maintenance" was to increase the understanding of the requirements, capabilities, and constraints of EVA (5). The anticipated problems and maintenance requirements of seven major areas of in-space maintenance and assembly tasks are discussed, with emphasis placed on the assembly of large structure and leak detection, location and repair. The discussion concludes with a tabulation of the major sources of malfunction and a distribution table of internal and external maintenance activities. Also included are the effects of the hazards of the space environment and the spacesuit on the astronaut and his efficiency as a space maintenance worker. Space tools are addressed in some detail. Performance characteristics and future capabilities of tools and accessories are considered. Manual locomotion and powered astronaut maneuvering were described and compared. Finally, a computer simulation technique for obtaining improved probability of mission success is described.

"Integrated Maintainability Criteria Development Technique" was a 1967 study and subsequent report done by Martin Marietta Corporation for the Air Force Aero Propulsion Laboratory at Wright-Patterson Air Force Base (10). From this study evolved a general procedure to develop maintainability design criteria for in-space maintenance. A matrix system was set up to provide an orderly method of assessing requirements and to present information in a manner conducive to logical trade-offs. The objective was to provide a technique for integration of maintenance support and system design decisions to improve overall system effectiveness. The major problems of development of valid input data and quantification of support concepts to allow more sophisticated analysis of support system trade-offs were discussed, including the need for specifications and standard interfaces for standardization of in-space maintenance.

To summarize, the 1967 Martin Marietta report (1) clarified the problem of trade-offs and system development interfaces, (2) structured the analytical data requirements, and (3) examined the areas of data which are needed for analysis leading to a more realistic view of the maintainability development area with an increased capability to plan and justify research and development efforts.

In 1968, the Second National Conference on Space Maintenance and Extravehicular Activities, was held in Las Vegas, Nevada. The transactions of this conference consisted of reports on the various technical contributions and research in these fields. The conference was divided into seven sessions (15).

The first session dealt with the requirement for space maintenance, EVA, and design considerations affecting man's efficiency in performing space maintenance. The second session, entitled Spacecraft Maintainability and Reliability, concluded that the longer the mission life span, the more "maintainable" a spacecraft must be to maximize mission success. Space systems malfunction isolation was addressed, and a methodology outlined to determine how many and what system parameters should be monitored. A space maintainability analysis was developed to verify the concept, determine repair tasks, and evaluate the increase in probability of mission success.

The third session, Related Man-Machine Interface Problems, discussed the performance of manual work in space and concludes that weightlessness can reduce the efficiency of man. Space Maintenance Technology, the fourth session, studied (1) the hazards associated with various power sources for space tools, (2) the role of space manipulator systems, (3) quick-release fasteners for space application, and (4) tool design for EVA maintenance. Maneuvering-Unit Technology was the subject of the fifth session. Piloting problems, such as handling qualities, were discussed as well as the application of control moment gyros to maintain control and stabilization. Various powered astronaut maneuvering techniques and voice control were addressed. The feasibility and basic utility of hands-free precision control for EVA was proven.

In session six, Protective Systems, the areas of spacesuit development, portable life-support concepts, and portable environmental control systems were presented. Session seven proposed various space experiments and simulations. Examples of experiments included EVA using different types of maneuvering equipment and EVA for the purpose of conducting scientific experiments. Simulations involving evaluation of space mobility aids and tasks were outlined.

"An Assessment of the Practicality of Orbital Maintenance" is a technical paper written by Peter N. Van Schaik in 1968 (18). His paper defines orbital maintenance (also called space maintenance) as ". . . the technology whereby man locates, repairs or replaces malfunctioned components or systems while in orbit to continue the mission and not return to earth prematurely [18:1]." His conclusion is that for longer mission life spans, orbital maintenance and EVA provides the most advantageous solution and, in many cases, the only solution to adequate reliability. He believes tests involving spacecraft are necessary to increase the data baseline to the level for favorable maintenance decisions, and contends that without sufficient technical data, for maintenance design, orbital maintenance capability will not find its way on the next generation spacecraft.

Post-1970 Studies

The following reports and studies are of a more recent era and show a marked change in emphasis from EVA concepts to unmanned servicing concepts for on-orbit maintenance. They also show a stronger infrastructure in development of maintenance concepts early in system design and requirements determination. Contracted by the National Aeronautics and Space Administration (NASA), Martin Marietta Corporation published a two-volume report in 1975 entitled "Integrated Orbital Servicing Study for Low-Cost Payload Programs" (8; 9). In this report, various satellite maintenance concepts were studied and effectiveness comparisons were made.

This effort included an assessment of the relative value of the previously identified space maintenance concepts and an overall comparison of the expendable, ground-refurbishable, and on-orbit maintenance modes. Of the various concepts studied, the on-orbit servicer maintenance system was recommended. It is believed that this system is compatible with many spacecraft programs and would be the most cost-effective system. Also, spacecraft can be designed to be serviceable with acceptable design, weight, volume, and cost effects. It is also believed that orbital maintenance does not significantly impact the STS.

The pivoting arm on-orbit servicer was selected and a preliminary design prepared. It was stated that on-orbit servicing is best when (1) there are many similar spacecraft in orbit, (2) the program time is long compared to the spacecraft lifetime, (3) the spacecraft availability requirement is similar for comparative modes, and (4) the spacecraft cost is not too low compared to the launch cost. Module exchange was also selected to be the best approach to the problem of satellite maintenance because it satisfies the majority of the servicing operations with a single technique.

The total life-cycle cost, as well the impact to operational requirements and design, was considered. Standardization and interface control were emphasized. Modularization of a spacecraft requires many of the same design factors as standardization. For example, both approaches would benefit from standardized electrical connectors. Standardized spacecraft subsystems could be integrated into a modular design with minimum impact. However, the Space Replaceable Units (SRUs) of on-orbit servicing need not be standardized subsystems; they need only have standardized interfaces.

In 1978, Martin Marietta Corporation published the "Integrated Orbital Servicing Study Follow-On" report (6; 7). This report essentially picks up where the previous report ended. The conclusions of the 1975 Martin Marietta report were verified and extended in many areas related to the "how" of on-orbit servicing.

The study had two major objectives. The first was to continue development of orbital maintenance concepts that emerged from the 1975 study; and the second was to design, fabricate, test, and deliver certain equipment for One-g demonstrations of axial and radial module exchange in three control modes.

Martin Marietta Corporation has designed, manufactured, assembled, checked-out, and delivered a One-g servicing demonstration system which can be used to investigate and develop--"in a real time hands-on situation"--a broad diversity of the mechanism and control system aspects of module exchange. Volume III of the 1978 Martin Marietta report goes into great detail as to the design, specifications, characteristics, and capabilities of the One-g Servicing Demonstration System, the Engineering Test Unit (ETU), and the Servicer Servo Drive Console (SSDC). Each of these systems was assembled, checked-out, and put through various test modes and operations. The final testing involved mating of the SSDC with the ETU and performing a complete systems test. All operations of the full system were verified for proper operation. Although the system satisfied the contractual objectives, recommendations for improvements and refinements are presented in the following areas: (1) systems aspects, (2) mechanical aspects, and (3) electronics aspects.

Significant results and conclusions of the 1978 Martin Marietta report are as follows:

1. From an analysis of twenty-eight serviceable spacecraft designs, a valid set of servicer system requirements has been developed.

2. After examining the servicer system requirements, it was found that only five modular servicer mechanisms satisfied all of these requirements. Of the five, the axial/rear-radial servicer mechanism configuration, was chosen as the best.

3. Spacecraft can be designed to enhance orbital servicing as well as meet mission performance requirements.

4. In looking at the module exchange task, a preliminary servicer system design was generated.

5. The servicer design satisfies all other requirements, such as weight, stiffness, and torque.

6. A vital element in satellite servicing, the servicer control system (three modes), was developed.

7. A simulation and demonstration of the servicing module-exchange operation, using the servicer control system, were conducted.

8. Analysis revealed that on-orbit maintenance was the most cost-effective way to repair geosynchronous satellites.

9. In studying life-cycle costs, operations costs, rather than design, development, test and evaluations, or production costs, were found to be the largest.

10. A full-scale servicer demonstration system, representative of the design, was designed, fabricated, and delivered to Marshall Space Flight Center.

11. Further servicer and serviceable spacecraft system development is necessary for user acceptance.

An overview of Marshall Space Flight Center's (MSFC's) "Remote Satellite Services Program" is presented in a 1981 NASA Program Planning Summary (11). The satellite services program is shown to have been structured to provide a wide range of services to users of the space shuttle. These services include payload delivery, retrieval, servicing, repair, refueling, and large structure construction support functions at distances remote or detached from the orbiter.

The summary concludes that many of the capabilities required can be provided by a basic remotely controlled free-flying Teleoperator Maneuvering System (TMS) vehicle which can be incrementally modified through the use of add-on mission support/performance augmentation kits or robotics systems elements to provide the more advanced mission capabilities needed in later years. Briefly, the TMS provides modular design features to accommodate both early spacecraft delivery/retrieval mission needs, and the capability to evolve via the addition of dextrous manipulator/automated servicing mechanisms and advanced TV systems for accomplishing the more complex, robotic missions of the late 1980s-early 1990s.

The 1981 NASA report "Teleoperator Maneuvering System Study," is a thorough briefing on Vought Corporation's TMS (16). It includes design features, performance, costs, and schedules. The TMS is comprised of three segments: (1) the vehicle, (2) the shuttle orbiter payload by cradle with Airborne Support Equipment (ASE), and the Aft Flight Deck (AFD) control station. The vehicle is a reusable remotely controlled free-flying unit capable of satellite servicing, placement, and retrieval. It flies preprogrammed trajectories as well as being controlled from the AFD or the ground. The lightweight ASE cradle may be conveniently positioned along the payload bay length where it is attached using the standard sill and keel fittings. The cradle supports the TMS during the launch and reentry phases and houses the antennas, communication, video, and other avionics ASE necessary for vehicle man-in-loop control from the orbiter's AFD. The AFD installation is mission dedicated; however, the entire TMS operation is autonomous to the orbiter systems except for in-bay power and guidance initialization through the orbiter multiplex bus. Recorded data will also be stored by the orbiter.

The USAF Space Logistics Study Group, chartered by the Air Staff, was given the task of conducting an Air Force-wide study, using the USAF Space Plan as a guide, to develop evolutionary concepts for logistics support of space programs. Air Force Logistics Command (AFLC) was directed to lead the study with the affected major commands supporting the effort. The outcome of the study was released on 10 January 1983 and entitled "United States Air Force Space Logistics Concept Study" (4).

The study concludes that improved space systems supportability can be attained with several procedural and organizational changes. They include (1) consolidating logistics management at several locations, (2) establishing and enhancing liaison functions, (3) bolstering logistics staffs, (4) integrating existing support services, (5) increasing logistics involvement earlier in systems development, (6) standardizing support functions, (7) performing interservice support reviews, and (8) generally improving management communications. These changes will improve support responsiveness and economies of operation of the current logistics infrastructure while retaining a flexibility to adapt to the evolving needs of the Air Force mission is space. Appendices include a draft program development plan and program management directive. These documents outline manpower requirements, and management direction and procedures.

Summary

It is apparent that the trend in space research is to search for the most effective and efficient way to design, develop, and support our space assets. Even though much of the research is dated, the information presented is crucial to the ongoing and future studies of maintenance concept development for space maintenance. The latter research stresses the technical capabilities of developing and using a NON-EVA on-orbit maintenance concept in conjunction with designing satellites to effect modularity and standardization for greater economies of development and supportability.

The following chapter presents the methodology used to analyze the reports addressed in the foregoing chapter. Specific applicability of these reports to on-orbit repair capabilities and satellite design criteria will be discussed in Chapter IV.

CHAPTER III

METHODOLOGY

The Space Fox constellation introduced in Chapter I will be hypothetically brought through the acquisition cycle to have specific system characteristics to apply the data analysis. The system characteristics as set forth are:

1. An operational requirement for an earth coverage communications network.

2. A total of eighteen satellites.

3. A twenty- to thirty-year on-orbit mission life span.

4. A medium earth orbit of between 1,200 and 1,400 miles.

5. Three equally spaced orbits, six satellites per orbit.

6. Orbits separated by 120 degrees in right ascension and inclined at 74 degrees.

These characteristics make it possible to recognize data relationships and applicability to a specific NON-EVA on-orbit maintenance concept set forth in the research objective and further broken out into the research questions. The research questions will be used to support the NON-EVA concept that is specifically applicable to the Space Fox constellation. The research questions are restated below:

1. What technical capabilities are required to facilitate spacecraft NON-EVA on-orbit repair?

2. What spacecraft "design to build" criteria are required to facilitate NON-EVA on-orbit repair?

3. What economic factors must be considered in opting for spacecraft NON-EVA on-orbit repair?

Evaluation Parameters

The analytical process used in deciding which data to use in demonstrating the feasibility of NON-EVA on-orbit repair concepts consisted of reviewing the documentation available for applicability of technical, economic, and design feasibility to successfully perform NON-EVA on-orbit maintenance on Space Fox satellites. The analysis recognized the data relationships and applicability in developing the specific maintenance concept required to support NON-EVA on-orbit repair.

Operational Definitions

Technical capabilities refer to the ability to develop and manufacture the necessary equipment to support NON-EVA on-orbit repair concepts. This equipment is both the actual satellite system and subsystems and the visiting system used to perform the maintenance. Directly related to these technical capabilities are the "design to build" criteria. These criteria must conform to the system operational requirements and the maintenance concept. "Design to build" criteria consists of specific requirements such as modularity, standardization, interchangeability, and mounting provisions and have a direct impact on system design.

Another factor that impacts system design is economic considerations. Essentially, the decision as to what type of maintenance concept is to be utilized must be the most economical over the life-cycle of the system. The ideas of economies of scale in production and development and the expense of designing for human capabilities in space, as well as reliability versus maintainability, are major areas analyzed in economic trade-off studies.

Criteria Assessment

The criteria used in choosing the data applicable to the technical capabilities required for NON-EVA on-orbit spacecraft repair must be divided into two areas. The first is technical capabilities in building the orbiting system. Data on the amount of reliability that can be built-in compared to the on-orbit mission life span is required. The ability to include modular design with the necessary electrical interfaces and quick disconnectors will be included. The second area of technical capabilities analysis is the type and abilities of the maintenance servicer. The criteria for the servicer is that it must be capable of modular exchange which includes the tasks of remove, flip, relocate, and insert. The servicer must also be capable of medium earth orbit operation and reorientation of the satellite.

To facilitate the NON-EVA on-orbit repair of a satellite, certain design characteristics are essential. The areas specifically evaluated are standardization of the bus, pallet, power supply, and other subsystems to include the electrical interfaces. Modularity and interchangeability, as well as accessibility of the space replaceable units (SRUs) is analyzed. The need to build-in quick disconnects and fasteners is the final design criteria addressed.

Economic considerations are analyzed in the areas of reliability and redundancy costs versus the cost of including a maintainability capability. Other cost criteria considerations are in the areas of ground refurbishment, human factors involved in EVA maintenance techniques, and visiting system (NON-EVA) maintenance techniques.

Data Validation

The reports used in this research effort included joint NASA and DOD studies. These studies are inherently more credible due to the different areas of responsibility. NASA's responsibility is to the commercial, civilian, and international users. These users want to be shown the technical and economical feasibility of a system. On the other hand, the DOD requires much tighter specifications and adherence to those specifications and regulations. These differences tend to ensure the studies are accurate and results are valid.

The 1975 and 1978 Martin Marietta reports interfaced, integrated, shared and compared data with the TRW Corporation. This interface is a method of validating both methodology and results. Most of the other references cross-reference each other in the bibliography. "Extravehicular Space Maintenance" by Grumman, references Charles May's 1965 report, "Maintenance in a Weightless Environment." Four studies list Bell Aerospace Corporation's "Study of Space Maintenance Techniques," in their bibliography. This shows a respect for the expertise and authority of the individuals doing research in the area of space maintenance. It also lends credibility to those research efforts.

Summary

The credibility of the documentation used for this research effort is reflected above. As the material is synthesized and analyzed through the criteria outlined in this chapter, it will support the fourfold research purpose and answer the research questions as they specifically apply to Space Fox. The results and findings of the critical analysis are presented in Chapter IV.

CHAPTER IV

RESULTS AND FINDINGS

Introduction

The objective of this chapter is to show the relationship between developing the maintenance concept and maintenance plan, and an orbiting system that can be repaired by NON-EVA techniques. In developing this relationship, the three research questions will be answered by bringing the constellation Space Fox from conception to deployment. To facilitate this analysis, it will be assumed that the mission analysis of Space Fox is complete. This analysis created the six characteristics stated in Chapters I and III. Concurrent with mission analysis is operational need justification and technological base analysis. These two factors are assumed to be adequate to get the Justification Major System New Start (JMSNS) approved. Once the JMSNS is approved, the program enters milestone Ø (Program Initiation). The next step is the concept development.

Concept Development Phase

The function of this phase is to identify and evaluate alternatives. Gross estimates of satellite "design to build" criteria develop and are evaluated. To facilitate NON-EVA maintenance techniques, the satellite must be designed to be modular with standardized placement of the Space Replaceable Units (SRUs). There are two basic ideas for placement of SRUs. The first is "status quo." The other is "maximum STS efficiency" (9:Ch.V-2). Status quo is a two-tier placement of the SRUs in the satellite, and creates a problem for the servicer by requiring two docking ports for the servicer and resulting in the spacecraft not fitting well into the STS cargo bay (9:Ch.V-3). A flat disk, single tier satellite configuration compatible with the inside diameter of the cargo bay and the TMS, represents the maximum STS efficiency. It also only requires one docking port for servicing the SRUs (9:Ch.V-5). This design also lends itself to better accessibility of the SRUs and allows more freedom in the ability of the servicer to interchange modules. In addition to the mechanical fastening of the servicer to the satellite, four types of connectors are involved in designing the satellite: (1) electrical, (2) waveguide, (3) fluid, and (4) thermal. Signal multiplexing is the preferred way to decrease the number of pins going to each black box; the same idea is used to distribute power. One voltage is transmitted to each black box; and within the box, the appropriate voltages and frequencies needed are converted. This decrease in pins simplifies the mating and demating of the SRUs with the satellite and spares rack of the servicer. COMSAT laboratories have conceived a basis for waveguide connectors and have found it possible to avoid fluid connectors by combining the thruster set and the propellant tanks in the same module. In thermal aspects, the tendency is to treat each module separately and minimize inter-module heat flow (9:Ch.V-6).

Since Space Fox has a mission requirement for a twenty to thirty year on-orbit life span, the question of reliability is a major concern in the technical capability area. To achieve a system mission success goal of .95 for a short five-year mission, the sum of all equipment failure rates must total about one failure per million operating hours (15:Sec.II,Ch.1-1). Redundancy is one way to achieve reliability but not all equipments lend themselves to operating redundancy techniques. In many cases, system characteristics change when one or more of the parallel redundant equipments are inoperative (15:Sec.II,Ch.1-3). Another factor against redundancy is, for a system in orbit for an extended period of time, the use of extensive redundancy is not practical. The weight factors would become constraining (1:8). These negatives lead to analyzing modular replacement and the interfaces needed for alignment. The current SRU interface mechanism designs are predicted to have an alignment accuracy of 0.001 inches in transition and 15 arc seconds in rotation. These data lead the designers to believe that instruments/sensors can be replaced with a servicer mechanism, in most cases, without changing the current interface mechanism design (9:Ch.V-7).

A factor that always plays a part in the design criteria versus the technical capabilities is economic considerations. These considerations require trade-off studies. The first area of consideration is reliability and redundancy versus maintainability. For missions of long duration, the necessary reliability can result in inordinately high cost for the system (5:Ch.1-1). The extra time and weight required to develop the appropriate/extensive redundancy to attain the required levels of mission success increase the system cost out of the users capability. Designing in a maintainability option can decrease the system cost over the long run. Once the concept of maintainability is established, there are two options of how to do it: (1) ground refurbishment, and (2) on-orbit repair. An example of a cost analysis was done by Martin Marietta. It involved forty-seven satellite designs over a twelve-year period. The conclusion of this analysis was that on-orbit repair realized a savings of greater than nine billion dollars over the expendable mode, and four billion dollars over the ground refurbishment mode (9:Ch.I-1). Within the on-orbit mode, cost comparisons must be done between the EVA and NON-EVA methods. Anytime man is involved, additional cost will be incurred. This is due to the hazardous environment in space and the requirement to enclose man in an artificial environment.

Along with design criteria, and technical and economic studies, the preliminary maintenance concept is addressed. Maintainability characteristics need to be designed into system equipment only to the extent to which maintenance activities are planned (10:67). At this stage in the system life-cycle, the details of the system are not well known; existing maintenance capabilities are well known. Close cooperation and communication between the engineers and logisticians is extremely important at this point to set the ground work for the rest of the system development. The capabilities of the maintenance servicer must be analyzed at this time to facilitate selection of the proper design and system engineering for the most effective logistics support capabilities.

The pivoting arm servicer developed by Martin Marietta has a module mass range from 0 to 700 pounds, and a tip force greater than 20 pounds in a worst-case configuration. With minimum degrees of freedom, it can remove, flip, relocate, and insert a module from the stowage rack to the satellite and vice versa (9:Ch.VII-4). Requiring no direct human intervention, its operating altitude is limited only to the capabilities of the delivery system it is interfaced with. The TMS is the delivery system the pivoting arm servicer would use. The power supply interfaces are designed to be compatible as are the data exchange interfaces between the shuttle computer system, the TMS and the pivoting arm (11:26). Depending on whether the satellite uses the "status quo" or "maximize STS capabilities," SRU placement design will influence the type of capabilities selected for the pivoting arm between radial and axial manuevering techniques. This design will also determine whether the pivoting arm will be able to dock once in the center of the satellite or be required to dock more than once on the sides of the satellite to achieve modular replacement.

As these criteria, capabilities, and considerations are analyzed and trade-offs established, the system moves towards milestone 1, requirements validation. Once this milestone has been reached and the appropriate reviews have been accomplished, as well as Secretary of Defense approval, the program moves into the next phase: demonstration and validation.

Demonstration and Validation Phase

The function of this phase is to achieve system optimization. Because Space Fox has a long mission life span, maintainability functions must be designed-in. In addition to drawings, specifications, and other design data describing the equipment, a system analysis of the mission is made to screen out those items which should not be considered for maintenance either because the likelihood of failure during the mission is too remote, and the consequences of failure, relatively insignificant or the available response time or other such considerations of importance, make it obviously unwise to attempt maintenance so that redundancy or back-up systems are the clear choices (10:75). In a spacecraft system, the amount of weight initially allocated for equipment redundancy or in-flight repair must be based upon early reliability estimates (5:Ch.6-1). Although reliability is considered a logistics element, it is an engineering function. Reliability is achieved through contractual specifications and requirements. Configurations of the spacecraft considered for maintenance are important for four reasons that involve design criteria, technical capabilities, and economic considerations. These four reasons are as follows:

> "1) The sizes and shapes of the spacecraft as stowed in the payload bay are necessary to calculate potential launch sharings and costs;
> "2) The operating configuration of the spacecraft as compared to the stowed configuration in the payload bay is necessary to determine requirements for reconfiguring the operating spacecraft to fit back into the payload bay for ground refurbishment;
> "3) The operating configuration is necessary for investigating docking considerations and movement of external servicing devices over the spacecraft surfaces; and
> "4) The current configuration is necessary to help determine if, and how, a spacecraft should be configured for servicing [9:Ch.I-5]."

Another factor in design criteria that must be decided is the type of stabilization, 3-axis or spinning. To facilitate on-orbit repair, the optimal mode is 3-axis. The gyro mechanisms can be calibrated on the ground and modular replacement is possible, and reinitializing the satellite in orbit is much easier to achieve (9:Ch.III-11). If the two-tier requirement is chosen for configuration, analysis shows that if the most reliable equipment is placed is the second tier and not designed for on-orbit replacement, and the least reliable in the first tier where they could be replaced on failure, the 95 percent potential savings for the two-tier design could still be obtained. The preferred alternative is the one-tier modular exchange capability (8:Ch.V-3). As the alternatives for the satellite design are analyzed, the maintenance concept is iteratively updated. Of the many approaches to providing servicing functions, modular exchange was selected for maintenance concept evaluation because it satisfies the majority of the servicing operations with a single technique (6:Ch.II-1). Modular exchange can provide the servicing functions of (1) repair failed equipment, (2) repair degraded equipment, (3) overcome design failures, (4) replace/replenish worn-out equipment, and (5) update equipment with new models (6:Ch.II-2). This is a pure remove and replace, on-equipment concept. No further repair levels or capabilities are included. This alleviates the need for a direct man-in-loop function. The SRUs will employ built-in test equipment. This test equipment would be capable of monitoring, fault detection, isolation, and prediction (5:Ch.8-2).

With the completion of these optimizing alternative selections, a prototype of the systems and subsystems, for testing and demonstrating operational capabilities, is the next step. At the same time, the maintenance servicer that best fits the configuration and design criteria of the satellite needs to be prototyped. The reports and recommendations from this phase go through the same review process as required to reach milestone 1. But this review results in milestone 2, program go-ahead. Once the go-ahead is approved, the system goes into full-scale development.

Full-Scale Development Phase

The objective of this phase is to design, develop, fabricate, and test the system to include the support equipment and documentation. The requirements of design to facilitate NON-EVA maintenance techniques are as follows: (1) use a central docking system; (2) arrange SRUs for single docking per spacecraft servicing; (3) locate docking port such that the direction is normal to solar-array drive axis direction; (4) design the solar arrays to be highly reliable, non-replaceable units (NRU) and non-retractable; (5) other appendages need not be retractable once on-orbit; (6) design satellite to use most of the orbiter cargo bay diameter; (7) internal structure of modules and locations are of web type; (8) use between ten and thirty modules; (9) include standardized subsystems that are structurally and thermally independent;

(10) use signal multiplexing and single source power to simplify mating and demating of SRUs (8:Ch.V-3; 6:Ch.V-6). To ensure that these design criteria are met, schematics must be developed which illustrate components, black boxes, plumbing or electrical networks, and information flow (14:21). The subsystems that can be SRUs include avionics, fuel cells, and photo-voltaic cells, as well as other propulsion and power subsystems (14:20,76-77). Other requirements for obtaining the required reliability involve the technical development of Class "S" (space) reliable parts. All contracts specify the use of this class of components. They require stringent quality, test, and checkout during and after production (4:Ch.V-2).

The operational requirement to have eighteen satellites lends itself to both economies of scale and standardization in development. Advantages of on-orbit servicing are greatest when there are many similar spacecraft in orbit (9:Ch.II-9). The more of something that is required to be built the cheaper each individual unit or part becomes. Module size can be standardized as can the subsystems controlling the conversion of voltages and frequencies needed within the black boxes. This has been one of the major problems in cost of the past systems. Each one has been unique in design and function, so that the contractors were consistently operating at "state-of-the-art" constraints. This increase risk to both the contractor and the user. When risk of not achieving mission success and the required availability is very high so is the cost of system development. The inclusion of logistics support elements in a system that requires maintenance also makes it easier to estimate the amount of spare modules needed to facilitate the required probability of mission success over the systems on-orbit life span.

As the specifics of the logistics support requirements are analyzed against the design criteria, technical capabilities, and economic considerations of Space Fox, the actual maintenance plan for performing NON-EVA on-orbit maintenance evolves from the maintenance concept. In general, obtaining the desired probability of mission success will require both on-orbit repair and equipment redundancy (5:Ch.7-2).

The maintenance plan will include exactly which modules will be designed as SRUs and NRUs. This is imperative so that when the servicer is sent up to repair the satellite(s), the computer on the ground can program the servicer to replace the appropriate SRU and its exact location in the web. The selection of the servicer is the one that achieves the best balance between maximum simplicity and maximum versatility, and yet is not too restrictive on the spacecraft designer. The length of the servicer mechanism when stowed in the cargo bay is important because it occupies space otherwise usable by other payloads. The total stowed length of the TMS-mounted 6 degree-of-freedom pivoting arm mechanism, including stowage rack and docking mechanism is 61 inches (6:Ch.V-11). The interface mechanism used to fasten SRUs into the repairable satellite is compatible with the associated stowage rack of the servicer (6:Ch.V-20).

The recommended servicer control system involves supervisory control with remotely manned back-up control and involves relatively standard force and position sensors feeding into a control electronics assembly, which would, in turn, tell the mechanical devices, links, rollers, push rods, bell cranks, worm gears, spring-loaded ball detents, and guide rollers, what movements are required to perform the task. Power will be provided by the carrier vehicle through a distribution interface (6:Ch.V-29). Once the test, evaluation and compatibility of the prime equipment is complete and development of the systems is reported to be satisfactory, an additional review and approval is required to meet milestone 3, production and deployment. This is also the final phase that a system goes through in the acquisition cycle.

Production and Deployment Phase

Test and evaluation of the systems continue throughout this phase to ensure design criteria, technical capabilities, and economic considerations of both the satellite(s) and the maintenance servicer are met in facilitating the NON-EVA maintenance plan. The deployment of the satellites in Space Fox will be intervally timed. This allows for a degree of operation early in the constellation development. Data feedback from these earlier deployed satellites is used to update the system design characteristics and modify the maintenance plan, as required, and to the extent feasible in the satellites to be launched next. Continuous feedback monitoring makes it possible to ensure mission success throughout the system life-cycle by incorporating the changes and modifications necessary.

Summary

This chapter addresses the development of Space Fox through the acquisition cycle. During this development, the evaluation parameters set forth are identified and detailed to answer the research questions. The relationship between system development and the development of the maintenance concept and plan in supporting NON-EVA on-orbit maintenance techniques is also discussed. The final chapter will present the conclusions and recommendations brought forward by this development.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The most significant conclusion is that there is no technical or long-term economic reason why NON-EVA on-orbit maintenance techniques and concepts should not be established as an ongoing Space Transportation System (STS) capability. Related conclusions supporting the major one are as follows:

1. Design of a satellite to facilitate NON-EVA on-orbit repair capabilities is straightforward, with acceptable weight and cost effects.

2. On-orbit servicing is a feasible and useful method of significantly reducing spacecraft program costs.

3. On-orbit maintenance is the most cost-effective mode for maintenance of those systems that have many similar spacecraft in orbit, when the program life is long compared to spacecraft lifetime, when the spacecraft cost is not too low compared to launch cost, and when the satellite is in MEO or HEO (geosynchronous) orbits.

4. The evolving STS is designed to support on-orbit maintenance.

5. On-orbit servicing and high redundancy together are cost-effective when very high availability is required.

6. A single on-orbit service development can satisfy the requirements of performing on-orbit maintenance of orbiting systems.

Conclusions concerning the maintenance servicer include: (1) only the on-orbit service is applicable to both TMS and orbiter-based missions, (2) on-orbit servicers can accommodate a sufficient variety of module metrics to avoid an excessive spacecraft modularization penalty, and (3) the stowage rack and supporting structures can use standard aerospace materials and construction techniques.

One further area that is important in acceptance of NON-EVA on-orbit maintenance techniques is user acceptance. Conclusions in this area are that user need guarantees that servicing will be available and assures that it will be cost-effective. Finally, building, flying, and servicing a serviceable satellite is necessary to obtain widespread acceptance of on-orbit repair.

Recommendations

There are endless areas for further research in the area of developing the design of the satellites and the servicer to facilitate NON-EVA on-orbit maintenance concepts and acceptance of this technique. In the area of management, two recommendations are: develop an on-orbit servicer implementation plan and develop a technique for spacecraft program managers to select maintenance modes. Economics aspects could be researched by investigating the availability, lifetime, and servicing strategies with a reliability simulation. Major engineering work needs to be done in this area. But to accomplish this level of research, funding must be appropriated. I recommend that the individuals directly involved in promoting the advancement of both the civil and military aspects of space exploration work together towards this end.

1. Anton, G. Myron, Jr. Space Systems Maintenance Evaluation Model. Seattle: Boeing Company, [23 September 1964]. AD 466815.

2. Blanchard, Benjamin S. Logistics Engineering and Management. 2d ed. Englewood Cliffs NJ: Prentice-Hall, Inc., 1981.

3. Cilvik, Colonel Reginald M., USAF, ed. Managing the Air Force. 3d ed. Reference text for Department of Leadership and Management, Air War College, Maxwell AFB AL, 1982, Chapter 10, pp. 10-3, 10-9.

4. Davidson, Colonel John K., USAF. Final Report--AF Space Logistics Study Group. 10 January 1983.

5. De Marino, D. Extravehicular Space Maintenance. Bethpage NY: Grumman Aircraft Engineering Corporation, [15 December 1966]. AD 836374.

6. De Rocher, W. L., Jr. Integrated Orbital Servicing Study Follow-On. Vol. I. Executive Summary Final Report. Contract NAS8-30820 SA-5, 9. Data Procurement Document No. 446. MCR-77-246/N79-19065. Denver: Martin Marietta Corporation, [June 1978].

7. ________. Integrated Orbital Servicing Study Follow-On. Vol. III. Engineering Test Unit and Controls Final Report. Contract NAS8-30820 SA-5, 9. Data Procurement Document No. 446. MCR-77-246/N79-19067. Denver: Martin Marietta Corporation, [June 1978].

8. ________. Integrated Orbital Servicing Study for Low-Cost Payload Programs. Vol. I. Executive Summary Final Report. Contract NAS8-30820. Data Procurement Document No. 448. MCR-75-310/N76-11210. Denver: Martin Marietta Corporation, [September 1975].

9. ________. Integrated Orbital Servicing Study for Low-Cost Payload Programs. Vol. II. Contract NAS8-30820. Data Procurement Document No. 448. MCR-75-310/N76-11211. Denver: Martin Marietta Corporation, [September 1975].

10. Holmes, A. E., W. S. McQuay, and J. F. Costick, III. ∫MCdt Integrated Maintainability Criteria Development Technique. Denver: Martin Marietta Corporation, [September 1967].

11. Marshall Space Flight (MSF). Program Planning Summary. Space System Group, February 1981.

12. May, Chester B. Maintenance in a Weightless Environment. Air Force Aero Propulsion Laboratory, Wright-Patterson AFB OH, [March 1965]. AD 630807.

13. National Space Policy. White House Press Release. Date: 4 July 1982, p. 7.

14. Seale, Leonard M., Walter E. Bailey, and William E. Powe. Study of Space Maintenance Techniques. Directorate of Aeromechanics, Aeronautical Systems Division, Wright-Patterson AFB OH, [May 1963]. AD 406776.

15. Second National Conference on Space Maintenance and Extravehicular Activities. Sponsored by Air Force Aero Propulsion Laboratory and the National Aeronautics and Space Administration in cooperation with the North American Rockwell Corporation. Las Vegas NV, 6-8 August 1968. AD 688246.

16. Teleoperator Maneuvering System Study Mission Requirements and System Definition. Report No. 2-32500/1R-52961, National Aeronautics and Space Administration in conjunction with Vought Corporation, 2 December 1981.

17. U.S. Department of the Air Force. Equipment Maintenance Policies, Objectives, and Responsibilities. AFR 66-14. Washington: Government Printing Office. 15 November 1978.

18. Van Schaik, Peter N. An Assessment of the Practicality of Orbital Maintenance. Technical report presented at the AIAA Conference on Space Program Issue of the 70s, Seattle WA, 28-30 August 1967. AD 658454.

END

FILMED

12-83

DTIC