# MAINTAINABILITY OF MANNED SPACECRAFT FOR LONG-DURATION FLIGHTS

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Volume II

TECHNICAL REPORT

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# ABSTRACT

A study performed under Contract NAS2-3705 (NASA, OART-MAD, Ames Research Center), entitled "Study of Maintainability for Long-Duration Manned Space Flight," evaluates the influence of maintainability in sustaining a high level of reliability throughout long-term missions. A 99% probability of crew survival is a basic constraint in the analysis. Spacecraft of four representative but widely varying missions, one Earth-orbital and one interplanetary each in the mid-1970 and the mid-1980 time periods, are examined to the replaceable component level. Detailed maintenance analyses of subsystems and components, vehicle configuration optimizations performed with a unique computer program, and statistical results of several hundred mission simulations are described and evaluated. The effects of hardware reliability and failure rates, skills, environmental factors, mission durations and resupply potential, and various resources are considered in many interrelationships. Optimum distributions of redundant and spare items to be included on board each spacecraft configuration for assuring mission success are identified, and their implications as to operational requirements and design philosophies are discussed. Tables, charts, and graphs summarizing analytical results and displaying parametric sensitivities are provided. Gross cost estimates also are included to indicate trends and to place the respective missions in context relative to each other.

The study indicates that no attempt should be made to apply a single maintenance philosophy to all subsystems unilaterally. Rather, specific maintenance philosophies by subsystem, or by component where necessary, should be used. This will require strong management control at all levels and very close design integration throughout program development. If an on-board workshop capability can be justified by maintenance requirements common to several subsystems, a substantial reduction in the weight of inflight support elements could be realized. Maximum commonality among components should be exercised for the same reason. Items requiring only a single spare to achieve a desired assurance level should be designed for standby redundancy where possible. Accurate, valid, and detailed design data on space hardware is lacking in many important areas; this should be developed and disseminated as soon as possible for future programs. Space mission planning can be enhanced by employing complementary optimization and mission simulation models to evaluate parameters affecting the maintainability and overall operation of manned vehicles.

Volume I summarizes results of the study and describes very briefly its approach and methods. Volume II discusses the study in detail, including source material and rationale, analytical effort, and explanations of procedures. Volume III is a compilation of the material developed during the course of the analysis.

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# FOREWORD

In February 1966, Ames Research Center of the National Aeronautics and Space Administration issued Request for Proposal A-11798(WEB-49) entitled "Study of Maintainability for Long-Duration Manned Space Flight." The introduction to that RFP reads, in part, as follows:

> "Even with anticipated future technology to permit an order of magnitude increase (over the reliability of current systems---ed.) in the mean time to failure, and using complete parallel redundancy of all components, it is possible to meet a minimal desired level of system reliability only for a period of a few months. For such longer missions, system restoration through in-flight maintenance probably will be necessary to insure reliability. To attain reliability by in-flight maintenance, the system must be designed for maintenance, and a working environment must be created that is compatible with maintenance. Studies are needed to identify the effect of a requirement for in-flight maintenance on system design, considering the crew as part of the system."

This report presents guidelines for system and subsystem maintenance concept selection, and in addition records conclusions and recommendations derived during the study effort.

A very significant aspect of the study was the initial task of collecting, reviewing, and distilling a great deal of reference material, listed in Section 11.0. Detailed determination of basic mission factors such as trajectories, boost requirements, rendezvous and resupply techniques, etc., and origination of basic configuration and subsystem design concepts and details were beyond the scope of the study effort. Rather, using such information as was applicable and available from various resources, the study team modified, extrapolated, or otherwise adapted this material for compatibility with characteristics of the space mission being considered. In this respect, the study is typical of the way modern research efforts depend so heavily on previous work performed by many technicians in many different disciplines. Consequently, the study group acknowledges its indebtedness to earlier research activities.

A key factor in accomplishing the study is the computer programming technique employed for optimizing mission vehicle configurations. As described in greater detail in Section 3.5, the program is designed to achieve the desired level of overall system reliability by adding parallel redundancy, standby redundancy, or spares in the most "cost"-effective manner to an initially nonredundant system. This approach involves the determination of system, subsystem, and component operational characteristics and reliabilities, the identification of maintenance tasks to be performed, the kinds of skills that must be included within the flight personnel, and numerous other support requirements premised on accomplishing inflight maintenance (e.g., availability of appropriate technical data). "Cost" as used in this context can be considered in terms of weight, volume, repair times, etc., as well as dollars. The study group believes that this optimization technique, used in combination with full mission synthesis and simulation, comprises an analytical method that engenders a very high degree of confidence in the results obtained.

# 1.0 STUDY OBJECTIVES

Future long-duration manned space missions will require a drastic improvement in spacecraft capabilities to attain satisfactory probabilities of mission accomplishment. Increases in reliabilities of parts and assemblies, although mandatory, will not be sufficient in themselves to achieve the overall levels of assurance that are sought. The solution lies in the inclusion of appropriate on-board resources to augment or maintain, through the mission, the high reliability level that a spacecraft initially possesses. Three alternatives are available: (1) provide redundancies, (2) perform manual fault correction, or (3) incorporate a selective combination of the first two. Recognizing that certain redundancies will be necessary to accommodate operational or remedial requirements, it is evident that numerous opportunities also will exist for using crew capabilities effectively to perform maintenance. This study seeks to determine areas of such utilization, to develop an optimum approach to item (3), and to accomplish the following objectives:

a) Identify subsystems that are sensitive to maintenance philosophy; identify the effect of inflight maintenance requirements on their design, operation, and cost.

b) Specify, for subsystems and the overall spacecraft system, variations or additions that are needed to meet various levels of maintenance requirements.

c) Determine the effect that requirements for inflight maintenance will have on the development and performance of crew functions.

d) Develop maintainability design criteria for space vehicles, to be applied by designers of future systems.

e) Recommend maintenance philosophies for various types of space missions.

f) Identify areas warranting additional study and research on maintainability requirements and provisions.

When man embarks on a long-duration, unsupported space mission, design of the vehicle must include certain characteristics that would not necessarily be needed in an unmanned spacecraft. Chief among these is the life support/environmental control system. By its very nature, the life support function involves continuing, periodic manual servicing of several elements for which there are no known means of automation. Thus, some degree of scheduled maintenance becomes a mandatory requirement during a long-term manned mission, and must be planned for from the beginning. With on-board maintenance a foregone conclusion, the following objectives also become important: (1) to determine the extent of scheduled maintenance that could be expected, (2) to determine the kinds of activities and capabilities that would be involved, and (3) to determine the relationships of scheduled maintenance to any unscheduled restoration actions that might be performed. It should be noted that, throughout this report, the term "maintenance" generally refers to the unscheduled variety unless otherwise stated, or when the meaning is obvious from the context.

# 2.0 CONCLUSIONS AND RECOMMENDATIONS

Conclusions and recommendations are derived from the analytical work performed during the study. To better understand the following discussion, and to avoid detailed repetition, the reader should review the "Definitions of Terms and Abbreviations" in Section 3.3 before evaluating the statements made in this section. The most significant terms are defined briefly here for convenience:

- Crew Survival (Probability)---Assurance that no equipment-induced fatality occurs during a mission. In accordance with the work statement, this study used a factor of 99% probability of safe crew return as a mandatory requirement before any other mission assurances were considered.
- Degree of Maintenance---An arbitrary division of the spectrum of possible concepts for performing unscheduled maintenance, increasing in order of complexity. Degree "0" is essentially fully automated, Degree "1" is limited to simple adjustments and manual switching, Degree "2" permits fault isolation and physical replacement with spares, Degree "3" expands Degree "2" to include on-board repair and more sophisticated support actions.
- Maintainability---The quality of spacecraft hardware incorporated in its basic design to permit the performance of maintenance.
- Maintenance---Actions necessary to ensure continued proper operation of a unit (scheduled), or to restore a faulty unit to its specified operating condition (unscheduled). Generally, the term "maintenance" as used in this report refers to the unscheduled variety, unless its meaning is obvious from the context.
- Mission Success (Probability)---Assurance that no equipment function is lost that would preclude completion of all mission objectives. In this study, no particular objective was specified; all mission success factors include 99% probability of crew survival as a prerequisite, and 99% probability of mission success was used as a data base for comparison.

This section has been organized into general and specific conclusions. Detailed study findings from which specific conclusions were drawn are stated in Sections 5.0, 6.0, and 7.0 of this volume, and are referenced in parentheses. Recommendations given in Section 2.3 are based, to a great extent, on the areas requiring additional technical research, as reported in Section 10.0.

## 2.1 GENERAL STUDY CONCLUSIONS

Implementation of many of the conclusions and recommendations will be a matter of management concern. For instance, it might have been inferred from some sources that subsystem maintenance concepts can be developed and implemented independently. <u>This is not the case</u>, as pointed out in Item 1) below. The principle of developing maintenance concepts for each subsystem, and implementing them to achieve an effective total spacecraft, will require closer

control and coordination between subsystem design organizations than would be required if a single arbitrary concept were levied on all systems. A second example is that of component commonality, and this is where configuration management takes on an added dimension. There are a number of subsystems that could be designed with a larger number of common modules or components. Achievement of both the above goals will require very intensive intersubsystem discipline and will involve a high degree of management cognizance to provide the positive direction that will be necessary.

1) Development of Maintainability Concurrent with Hardware Design---Because the requirements for maintainability on a manned spacecraft form part of the hardware design criteria, it is necessary that maintainability characteristics be considered and their qualities included from the earliest phases of any design program for a manned mission. During the course of this study, it became apparent that no one maintenance philosophy could be applied unilaterally to all subsystems. Specific maintenance philosophies by subsystem, or by component if necessary, will be far more useful during design of the spacecraft. The maintenance concept for each subsystem must be determined by careful consideration of subsystem design features and parameters and the relationship of the subsystem to the spacecraft as a whole. For example, there are several subsystems that are on the borderline of a Degree "3" maintenance concept (see Section 3.4.1), and if enough common requirements can be found, it may be possible to specify a Degree "3" maintenance concept for all such candidates. The resulting benefit could be a reduction in total weight (including spares) required to support the mission. During spacecraft design and development, it will be necessary to modify the maintenance philosophies according to design progress, and to guide design with the planned baseline philosophy. In practice, this can be implemented only by a flexible and fully integrated team of maintenance and design engineers with decision autonomy restricted to the highest level of engineering management. (Problem areas should be resolved through mutual agreement at the working level wherever possible.)

2) Detailed Subsystem Study Required---Further research and study effort are necessary to define more accurately the components that comprise typical spacecraft subsystems and the parameters (weight, volume, failure rate, etc.) associated with each component. The more accurate the data inputs to study analyses, the more accurate the results obtained. The MARCEP and maintenance task analysis sheets contained in Volume III indicate the depth of detail required at the component level to perform this study. Considerable research was done to obtain the data needed, but it was found that good detailed data unfortunately was not readily available. Therefore, it is recommended that this area be studied further so accurate valid data can be made available to designers and future research and study programs.

3) Effectiveness of Study Technique---The technique of using both a mathematical model (MARCEP) and a general-purpose system simulation model to evaluate parameters that affect maintainability of long-duration manned space missions provides results that complement each other. This data should be very useful for planning future space missions. The results obtained from the mathematical optimization and general-purpose simulation models appear to be quite realistic. (Refer to Section 3.5 for discussions of these models.)

## 2.2 SPECIFIC STUDY CONCLUSIONS

### 2.2.1 DESIGNING FOR MAINTENANCE

1) Commonality of Spacecraft Components---Commonality of components and equipment, both within and between spacecraft subsystems, and between elements of the spacecraft, on-board experiments, and reentry vehicle, is one of the most important of all design objectives. Spares requirements decrease significantly, program costs are reduced, and training can be consolidated when a high degree of commonality is achieved (Sections 7.1 and 7.2).

2) Modularization---Modularization of components is an effective way to reduce the spares requirements and maintenance workload. The greater the commonality of modules the more effective is the spares usage, particularly for high failure rate components (Sections 5.1 and 6.1).

3) Design for Degree "2" Maintenance Concept---Subsystems should be designed for a Degree "2" maintenance concept (remove and replace) whenever practicable. This concept results in the most efficient use of spares, and the least weight and cost. As commonality of equipment increases, the concept becomes more advantageous. Particular exceptions to this concept include structural parts and large bulky items (Sections 7.1 and 7.2).

4) Maintenance Concept for One-Spare Items---If only one spare of an item is required to achieve the desired probability of assurance, it probably could be used most effectively as a standby redundant item, whenever system design permits (Section 8.2).

5) Battery and RCS Engine Service Life---The batteries and reaction control engines used in the 1975 near-Earth orbital mission have a service life of only 1 year, which adds about 16% to the workload. An improvement in the design life of these components can materially reduce the spacecraft maintenance requirements (Section 5.2.1).

### 2.2.2 IMPACT OF MAINTENANCE ACTIONS ON MISSION CONDUCT

1) Scheduled Maintenance Workload---The scheduled maintenance workload is significant. This varies from 114 to 147 man-minutes per day, on the average, for the four missions studied. The life support system is a major contributor to the workload. However, this situation can be improved considerably by designing the system to reduce the number and frequency of the filter, cartridge, and wick replacements, and by designing for quick replacement of these items where it is necessary (Sections 5.2 and 6.2).

2) Unscheduled Maintenance Workload---The crew workload imposed by unscheduled maintenance requirements is relatively low and does not significantly affect the operation of the spacecraft. No mission required unscheduled maintenance for more than 20% of the days involved; repair could be performed in under 2 hours for well over half of the days requiring unscheduled maintenance, and the mean daily repair time during such days was under 1 hour. Also, one of each type of crew skill is sufficient to handle the unsched-

uled maintenance workload, and the amount of EVA required for unscheduled maintenance is negligible (Sections 5.3 and 6.3).

3) Amount of Spares Actually Used---The actual average spares weight used to replace failed items is about 3 to 10% of the initial spares weight provided; and the maximum weight used during any one mission duration or resupply interval is about 16 to 20% of the initial weight provided for the 1975 missions, and 8 to 16% for the 1985 missions. Increased efficiency in the use of the spares provided occurs for the longer resupply intervals or mission durations (Sections 5.3 and 6.3).

4) Maintenance Resource Requirements---One of each crew skill type, two basic tool kits, and one of each other type resource identified (vacuum system, maneuvering units, etc.) are sufficient to handle all scheduled and unscheduled maintenance requirements, even if the equipment failure rates are substantially higher than predicted (Sections 5.3 and 6.3).

5) Airlock and Spacesuit Use---Airlock and spacesuit use required in conjunction with extravehicular unscheduled maintenance tasks is minimal. The requirements for scheduled maintenance are somewhat higher, but do not significantly affect spacecraft operations. As identified by previous studies, the EVA requirements for experiments have by far the largest influence on airlock and spacesuit use (Sections 5.3 and 6.3).

### 2.2.3 EFFECTS OF PARAMETER VARIATIONS

1) Effect of Mission Duration on Weight Added---The weight that must be added to a basic system to achieve 99% assurance of mission success increases by about 27 to 30% when the mission duration is doubled. Therefore, from the standpoint of the ratio of spares weight to total spacecraft weight, it appears that the longer resupply intervals should be used when there is a choice (Section 5.1).

2) Weight Increase for Mission Success and Crew Survival---The weight added to a basic system for 99% assurance of mission success is about 35 to 50% greater than that required for 99% assurance of crew survival (Sections 5.1 and 6.1).

3) Effect of Failure Rate on Weight Added to System---A 100% increase in failure rate results in a 27 to 30% increase in weight required for spares and redundancies (Sections 5.1 and 6.1).

4) Effect of Failure Rate on Repair Times---Changing the failure rate results in a proportional (linear) change in the average daily repair time, but has no significant effect on the mean maintenance task time (Section 5.1).

5) Effect of Varying MTTR or Repair Confidence Level---Increasing the mean-time-to-repair, or the confidence level desired for repair, above the baseline system results in significant increases in the weight added for redundancies and spares required to achieve designated mission assurances (Sections 5.1 and 6.1).

### 2.2.4 CONFIRMATION OF THE INFLIGHT MAINTENANCE CONCEPT

Maintenance is Required for Long-Duration Manned Space Flights---One of the interesting results of this study was the validation of an original premise that maintenance will be necessary for long-duration manned space missions. Not only was it determined that maintenance will be necessary, but that it also will be desirable and practical. Maintenance is necessary because it is virtually impossible to eliminate all maintenance activities. Maintenance is desirable because significant weight and cost savings can be made through maintenance in comparison with conventional forms of redundancy for most subsystems, as shown in Sections 4.0 and 7.0. Maintenance is practical because no factors were identified that precluded the performance of the maintenance tasks considered.

## 2.3 RECOMMENDATIONS

### 2.3.1 APPLICATIONS

1) Further Development of Study Data---Further evaluation of the data developed by the analysis runs conducted in this study should be made to identify additional pertinent data and relationships not covered within the scope of this study.

2) Documenting Subsystem Component Configurations---A document should be compiled that lists the subsystem components and equipment of each spacecraft configuration evaluated in this study, together with the basic component data such as failure rate, weight, etc., and additional component statistics derived from this study such as the quantity and type of redundancies allocated, the expected spares utilization, the expected repair task time, etc. The development of such a document with the information organized by individual component and combining the results of both manual analysis and computer mechanization, was not attempted during this study. However, a document of this type, with all information readily accessible, would serve as a baseline or guideline to industry for future spacecraft studies.

3) Use of Study Analysis Technique on Existing Systems---The concept of using an optimization model and a simulation model should be applied to an existing spacecraft/mission or to a spacecraft/mission in an advanced state of development. This would use a data base for existing equipment or for equipment in an advanced state of development, which should be broader and more accurate than that used in this study. The results of such an application would further validate the technique and yield results that could be used in refining existing mission planning. This study technique also should be applied to space experiment programs so that the maintenance requirements for experiments can be more accurately determined and be given appropriate consideration in the basic planning of a flight program.

### 2.3.2 RESEARCH

1) Degree "3" Maintenance Concept Evaluation---The concept of inflight bench-level maintenance (Degree "3" maintenance) should be studied in more detail to determine specific workshop equipment and weight requirements, and trades

should be made to determine the effect of Degree "3" maintenance on crew maintenance workload and on possible weight savings.

2) Mission Analysis Optimization on Costs---Cost algorithms for the effects of adding parallel, standby, and spares redundancies should be developed, and a mission analysis based on optimization of dollar cost at the component level should be conducted and compared with the results of a weight optimization for the same mission.

3) Mockup of Life Support Subsystem---A representative life support subsystem for at least a six-man crew should be mocked up in detail, and trial installations within a typical spacecraft cabin configuration should be made to determine the optimum placement of the subsystem for operation and maintenance. This is considered necessary because the study indicated that life support subsystem placement is a critical factor in spacecraft interior design.

4) Additional Study and Technology Research---A number of areas recommended for additional study or technology research are discussed in detail in Section 10.0. These recommendations generally include designing for modularization and commonality of equipment; investigation into the techniques required to repair large assemblies or structures in space, to minimize EVA or spacesuit use, and to enhance malfunction detection; further development of analysis methodology; better definition of the space environment; and determination of human performance in that environment.

# 3.0 STUDY LIMITATIONS AND METHODOLOGY

Limitations on the study scope, criteria developed and used in the study, and the method and techniques used in accomplishing the study are described in the following paragraphs. Study limitations are identified as ground rules, assumptions, and definitions. Ground rules, Section 3.1, were provided by NASA in the contract statement of work. The assumptions, Section 3.2, were made by the study team when required, and approved by the contract monitor. The definition of terms, Section 3.3, is a form of limitation in that it provides constraints upon the interpretation of certain words and phrases used frequently in the study.

Criteria were developed in the areas of maintenance philosophy, reliability, success, and maintenance requirement determination. Various criteria were used in making comparisons, or as standards in developing detailed study data. These criteria are discussed in Section 3.4.

Detailed descriptions of the manner in which the study was conducted, and of the techniques used, are provided in Section 3.5, Study Methodology.

## 3.1 GROUND RULES

The following ground rules were established by NASA for the performance of this study:

1) Two levels of technology were to be studied: the mid-1970's and the mid-1980's. (The terms "1975" and "1985" are used in the document as shorthand equivalents.)

2) At least two classes of missions were to be studied: the Earth-orbital mission, and the interplanetary mission.

3) Crew survivability of 0.99 or better was to be assured for each mission considered. This was a mandatory requirement within the overall context of mission success.

4) Crew sizes to be considered were to fall within the range of a minimum of six men to a maximum of 30 men.

5) No provisions for artificial gravity were to be considered for any mission.

6) Provisions for extravehicular activity and remote experiments were to be included in the study.

7) Mission goals were to be retained irrespective of any system compromises that might be incurred for maintainability purposes.

8) During extravehicular activities, no metabolic losses were to be charged solely to pressure suit influence. The only disadvantages to be considered were a loss in reach capability and in tactile sensation, and the effects of the spacesuit mass.

9) Mission success was defined as the probability of all equipment functions of the spacecraft being available for the required time during the mission, provided crew survivability requirements were first satisfied.

## 3.2 ASSUMPTIONS

Proper performance of the maintenance analysis required that certain assumptions and guidelines be established to ensure uniformity of effort and reduce the number of variables to a manageable level. Some of those used in this study include the following:

1) Unscheduled maintenance has priority over scheduled maintenance. Therefore, if maintenance resources (including crew skills) being used for scheduled maintenance are required for unscheduled maintenance, the scheduled tasks will be delayed until completion of the unscheduled task.

2) The mean maintenance repair times include the time from receipt of a fault indication through completion of the repair or replacement including checkout, and return of equipment to storage. They also include the effects of other assumptions given here when applicable. Where EVA is required, the time reflects that necessary for checkout and donning the spacesuit, egress and ingress through the airlock, and doffing and servicing the spacesuit. Part of the time required for prebreathing pure oxygen is assumed to be simultaneous with donning the spacesuit.

3) All high failure rate components used in fluid systems will be coupled into the system through the use of automatic shutoff-type quick disconnects.

4) All plumbing runs will be continuous where possible. All joints not expected to require disconnection will be brazed or welded.

5) Interconnecting wiring that might be expected to require repair will use wire wrap or similar techniques for high reliability and easily repairable connections. This will eliminate the need for soldering and potential associated problems.

6) Sufficient experience will have been gained on previous manned space flights that equipment will be designed for maximum ease-of-maintenance considering the available personnel skills, support equipment, and expected space environment.

7) Adequate lighting capability will be provided for both external and internal maintenance.

8) The pressurized spacesuit has a normal endurance capability of 3 hours with additional reserve capability of 1 hour.

9) Extravehicular activity (EVA) will require about 30 minutes for egress and ingress of vehicle (15 minutes each way).

10) Spares will be stored in a location readily accessible to the crew. An inventory will be kept of the spares on-board and their storage location to facilitate finding the correct spare when needed, and where applicable, to aid in determining new spares needed at resupply.

11) The probability of death during the mission is not considered in the 99% probability of crew survival that has been established as a mission requirement.

12) Where feasible, as an expediency for the study, it was assumed that the on-board inflight test system, which includes the display panel indications, would isolate a failure to the replaceable component, recognizing that certain design problems may be implicit in such an approach. This was assumed to be generally true for electronic equipment, in particular. Otherwise, it was assumed that test points would be available so a fault could be isolated to the replaceable component through the use of available maintenance and test equipment. It was also assumed that fault isolation could be performed without breaking electrical connections and that all components and test points would be accessible to a pressure-suited man where this was required.

13) Electronic components requiring replacement will be designed as plug-in modules.

14) Components will be designed where possible to require the use of no tools for their replacement, or a minimum number of standard tools.

15) Warning devices will be provided to give immediate warning of failure of critical components.

16) The interior volume must be sufficient to allow the crew to efficiently accomplish the mission.

17) The interior must be compatible with the maintainability requirements for accessibility, and operability requirements for monitor and control (refer to the maintenance equipment and inflight test subsystem discussions in Volume III).

18) Safety considerations such as rounded corners, easy access to spacesuits, rapid exits, and enclosure of experiments and operations that could contaminate the spacecraft interior shall be incorporated.

19) The interior of the vehicle, including all access hatches are sized for the 10th through 90th percentile crewman (Reference 1) in a pressurized spacesuit.

20) An area of privacy will be provided for each crewman.

## 3.3 DEFINITION OF TERMS AND ABBREVIATIONS

| | |
|---|---|
| AEV | Astronaut Encapsulation Vehicle |
| AMU | See "MMU" |
| Basic System | See "Single Thread System" |
| CM | Command Module---an Apollo-type vehicle. |
| CMG | Control-Moment Gyro---for spacecraft stabilization. |
| Commonality | The provision for identical replaceable items within a subsystem or between subsystems. Such items would perform similar, but not necessarily identical, functions and be directly interchangeable. |

| | |
|---|---|
| Crew Survival (Probability) | The probability that no fatal crew incident, caused by equipment failure, occurs during the mission. See Section 3.4.2. |
| Criticality Code | An arbitrary means to specify the relative impact of a component failure. |
| CRU | Combined Rotating Unit (See PCS)---the principal operational element of the PCS. |
| Degree of Maintenance | An arbitrary indication of the complexity of unscheduled maintenance to be performed. See "Level of Maintenance" and Section 3.4.1. |
| Downtime | The total elapsed time between cessation of a function and restoration of the function by automatic means or by crew action. |
| Dormant Failure Rate | The rate at which random failures can be expected to occur while a component is in an inactive state. |
| ERV | Earth Reentry Vehicle---An Apollo slashed cone type of vehicle. |
| EVA | Extravehicular activity. |
| GPSS | General Purpose System Simulation. See Section 3.5.4. |
| IMU | Inertial Measurement Unit---An element of a navigation and guidance system, consisting of a stable platform, gyros, accelerometers, and associated electronics. |
| Level of Maintenance | Commonly used to identify the location (complexity) of unscheduled maintenance, i.e., organizational, field level, depot, etc. Not used in this study because of the possibility of confusion. The defining term used in this study was "Degree of Maintenance" (see above). |
| LSS | Life Support System (includes Environmental Control System). |
| Maintainability | A quality of hardware design and installation which permits it to be retained in or restored to a specified operational condition, in accordance with predetermined requirements. |
| Maintenance | See "Scheduled" and "Unscheduled Maintenance." |
| Maintenance Concept | A plan for accomplishing scheduled and unscheduled maintenance developed during equipment design. The degree of maintenance to be performed to be specified in the general plan at the system, subsystem or component level. |

| | |
|---|---|
| Maximum Allowable Downtime | The longest continuous period of time for which the loss of a function can safely be tolerated. |
| MARCEP | Maintainability and Reliability Cost Effectiveness Program. A Boeing-developed optimization model used to augment basic spacecraft equipment component lists with spares and redundancies. See Section 3.5.4. |
| Mean Repair Time | The expected elapsed time required to accomplish a maintenance task under the anticipated work conditions. (Specified on MARCEP Data Sheets and Maintenance Task Analysis Sheets, see Volume III). |
| MEM | Mars Excursion Module. |
| Mission Success (Probability) | The probability that no loss of hardware function occurs that precludes completion of all mission objectives, with a 99% probability of crew survival being prerequisite to any degree of mission success. |
| MM | Mission Module---the main spacecraft pressurized compartment(s). |
| MMU | Modular Maneuvering Unit---integrated with backpack for astronaut extravehicular maneuvering. |
| MTBF | Mean-time-between-failures. |
| MTTR | Mean-time-to-repair. Average time required to restore an item to its original operating condition after a failure has occurred. Also specified on MARCEP Data Sheets and Maintenance Task Analysis Sheets as Mean Repair Time, the expected elapsed time required to accomplish a maintenance task under the anticipated work conditions. (See Volume III.) |
| Modularization | The design of large assemblies for easy repair at the subassembly level through the use of plug-in or bolt-on packages, to reduce the overall weight of spares required. Commonality between replaceable packages is a desirable goal of modularization. |
| Parallel-redundant Item | A duplicate unit not required for initial capability purposes, but provided in the system to enhance overall system reliability by operating simultaneously with the basic unit. |
| PCS, PCU | Power Conversion System (Unit)---Brayton cycle machinery to convert heat energy to electrical energy. |

| | |
|---|---|
| PLSS | Portable Life Support System (backpack). |
| Probability of Repair ($PR_x$) | See "Repair Confidence." |
| RCS | Reaction Control System. |
| Repair Confidence | The probability that an unscheduled maintenance task will be accomplished within a specified period of time. Designated in MARCEP as $PR_1$, $PR_2$,...$PR_6$. |
| RMU | Remote Maneuvering Unit---A remotely controlled extravehicular maneuvering and manipulating unit. |
| Scheduled Maintenance | Maintenance activity that occurs on a regular cycle that can be anticipated and planned for prior to system operation. |
| Simulation | A computer program that operates a system under anticipated real-time conditions (GPSS). |
| Single Thread System | The spacecraft equipment component list with items identified in the minimum quantities necessary to perform all required mission functions. (No spares, redundancies, or backup subsystems identified.) |
| SM | Service Module---A spacecraft element like the Apollo Service Module, housing midcourse propulsion and isotope power subsystems. |
| Spare Item | A separately stored unit available for exchange and replacement of an identical basic unit. |
| Standby-redundant Item | Same as parallel-redundant item, except operation occurs only when switched in at the time the basic unit fails. |
| Unscheduled Maintenance | All maintenance not classified as scheduled; including replacement of components due to random failures; repair of damage due to human error, spacecraft operations, or meteoroid impact; and adjustment required to meet established tolerances. |
| Volume | (as used in analyses) The space occupied by a component or item with no packing factor allowance or provision for maintenance "elbow room." |

## 3.4 STUDY CRITERIA

To conduct the study effectively for all of the missions studied, it was necessary to establish some criteria and procedural definitions to be used throughout the study. These are discussed in the following paragraphs.

### 3.4.1 MAINTENANCE CONCEPT

The primary objective of this study is to develop useful guidelines for evaluating the effects of different maintenance concepts on overall mission requirements. To do this in a logical and consistent manner, it is necessary to identify the factors affecting or affected by a maintenance concept, and to establish a selection criterion against which competitive concepts may be evaluated.

Maintenance Concept Selection---Establishing a logical approach to maintenance in a long-duration space mission is difficult because of the interplay of many contending factors. For example, appropriate maintenance may permit a manned system to attain an acceptable level of probability for crew survival and mission success, at a low weight penalty. But at the same time it must be recognized that the more maintenance time accumulated during the mission, the less crew time there will be available for scientific experiments or other mission tasks; this operates to lower the probability of completing the mission objectives.

The factors considered in determining preferred maintenance concepts for each type of mission are grouped as follows:

1) Operational and performance factors including:
   - Performance constraints (such as minimum crew survival probability)
   - Mission duration
   - Resupply interval (for near-Earth missions)
   - Crew size and available discretionary time
   - Scheduled mission events
   - Fault isolation technique.
2) Resource or cost factors including:
   - Dollar cost penalties
   - Mission module weight penalties (and the resultant effect on number of launches and launch costs)
   - Mission module volume penalties
   - Crew skill variations.
3) Hardware and design factors including:
   - Functional design constraints
   - Component life and failure rate.

Candidate maintenance concepts, and the selection criteria from which they are derived, must be defined so as to properly relate all of these factors.

The selection criterion used to evaluate alternate maintenance concepts was primarily the weight required to achieve a desired level of mission success

probability. This sterile criterion was tempered by the qualitative evaluation of the effect of a maintenance concept on other mission factors, including cost, crew skill and skill training requirements, equipment complexity, and expected design limitations, to mention only a few.

The following possible criteria for selecting a preferred maintenance concept were considered:

1) Minimum dollar cost penalty to obtain a preselected (fixed) probability of accomplishing stated mission objectives (reliability or crew survival).

2) Minimum weight penalty to obtain a preselected probability of accomplishing stated mission objectives.

3) Minimum crew manhour penalty for a fixed probability of success.

4) Minimum volume penalty for a fixed probability of success.

It would also be possible to use the opposite approach; that is, fix the maximum resource (dollars, weight, manhours, etc.) that could be expended, and select the maintenance concept so as to maximize the probability of success within the resource limit.

The actual resources that will be available for future space efforts are unknown at this time, however, and they could vary widely with calendar time. Therefore, any conclusions or recommendations based on an approach that maximizes success probability for some fixed resource limit would be of limited value. For this reason, it was decided that the selection criterion should be one in which fixed probability of success would be achieved at a minimum "cost" penalty. The general study approach allows the cost penalty to be measured in the form of dollar cost, weight, crew manhours, or combinations of these.

Maintenance Concept Definitions---The various maintenance concepts considered in this study for correcting unscheduled or random deficiencies may be defined in terms of the degrees of complexity of the maintenance action and the kinds and quantities of resources that would be required to restore the system after failure. These concepts cover a wide range of possibilities, varying from a Degree "0" maintenance, in which no unscheduled maintenance is contemplated so that the desired probability of success must be achieved by built-in automatic redundancy, to a Degree "3" maintenance in which maximum restoration of failed components can be accomplished. It must be remembered that the performance of scheduled maintenance has been established as an accepted requirement, for the purposes of this study. The general concepts for unscheduled maintenance activities are defined as follows:

1) The Degree "0" concept incorporates only provisions for automatic restoration of the system after failure.

2) The Degree "1" concept limits maintenance to adjustment of out-of-tolerance equipment and manual switching to activate standby redundant elements. Some fault isolation instructions and simple hand tools are needed but no special crew skills are required for this concept.

3) The Degree "2" concept incorporates provisions for physically removing failed components and replacing with a good spare. The maintenance actions in this concept include:

   - Fault isolation (and switching when a built-in standby also exists).
   - Breaking electrical and/or mechanical connections to the component package.
   - Mounting the spare component in the physical space of the failed unit.
   - Remaking electrical and mechanical connections to the component package.

   Fault isolation equipment, maintenance instructions and tool kits are required. Also, the crew must have greater knowledge of the system and possess greater technical skills than for the Degree "1" concept.

4) The Degree "3" maintenance concept allows repairs within the functional component packages. Such repairs may be made with the package in place in the system, or by removing the failed component to a more convenient work location. This concept involves maintenance actions similar to those for the Degree "2" concept, with the following additions:

   - Open or disassemble the component package.
   - Fault isolate to the failed part in the component package.
   - Repair and reassemble the package, using spare parts as appropriate.
   - Test and/or check out the repaired component.

   Cutting and joining processes are included. Sophisticated fault isolation equipment, maintenance instructions, and tools are required. Crew members must have highly specialized maintenance skills in addition to their capabilities for performing primary mission objectives.

All of these concepts are further defined by identification of the resources (weight, volume, manhours, etc.) that are expended to incorporate maintenance provisions for specific subsystems and components.

### 3.4.2 SUCCESS CRITERIA

The basic success criteria used for this study were requirements for 99% probability of crew survival and 99% probability for mission success. The 99% probability of crew survival as a mandatory requirement within overall mission success was initially established as a study ground rule by NASA. The spacecraft components considered for calculating crew survival probability were those found to be necessary for crew survival over the mission duration. The duration of the Earth-orbital missions was considered as the interval between

resupplies. The duration of the planetary missions was considered as the interval between successful injection into transplanetary trajectory and the arrival of the ERV on the Earth's surface. Mission success was defined as the probability of all spacecraft equipment functions being available for the required time during the mission, provided crew survival requirements were first met. Examples of some equipment necessary for mission success but not crew survival are: experiments, data management hardware, and recreation and exercise equipment.

As required, a 99% assurance of crew survival first was met in all of the study optimizations and simulations. A 99% assurance of mission success was also met or exceeded in all of the analyses even though a specific requirement for this level of success was not levied. Selection of a particular mission success goal was beyond the scope of this study. It should be noted, however, that the probability of crew survival is improved by some undetermined amount above 99% during the process of raising the probability of mission success to 99%. Further analysis, not attempted during this study, could be done to determine some other level of mission success below the 99% point (remembering that 99% probability of crew survival is always implicit), or to optimize the selection of components in such a way that 99% probability of both crew survival and mission success is achieved simultaneously.

### 3.3.3 RELIABILITY ASSESSMENT CRITERIA

Reliability (probability of mission success) and probability of crew survival were predicted for the various subsystems and missions as a part of the MARCEP process. For all reliability arrangements (that is, single thread, active parallel, switched standby or repair with spares), there were two important data inputs to the mathematical probability expressions:

1) Time (operating and allowable downtime)

2) Failure rates.

Operating time and allowable downtime were determined by examination of the profile and operations for each mission. To facilitate the computerized prediction process, all component experience was expressed in time. For those components whose failures were more dependent on the number of operating cycles than on hours of operation, the time entries in the MARCEP data sheets represent an equivalent opportunity to fail.

Selecting suitable failure rates for system components would, in general, require consideration of several influencing factors, including:

1) Operating environment (vibration, thermal, radiation, etc.)

2) Operating load (percent rates)

3) Specific component (by manufacturer's part or specification number) that might be selected, as influenced by dollar cost and development schedule limitations.

For this study of future space systems, however, the engineering definition of components was not sufficiently detailed to allow precise assessment of the effects of these factors. For this reason most component failure rates were selected by the following method.

First, the following basic assumptions were made:

1) Procurement constraints based on cost or schedule considerations would be the same as currently encountered in NASA programs. Therefore, part and component failure rates would be as good as, or better than, military standard.

2) Hardware for the 1975 mission would be essentially the same as that now in existence or under development in 1967.

3) Reliability growth for most component types would continue at the same rate as had been experienced over the past 5 years.

Next, failure rates for each component type were found in several sources to establish a feasible range. The sources of these data were many and varied. The major portion of the data sources used were made available from The Boeing Company, Aerospace Reliability Data Center. This data center provides support to all Aerospace Group programs and also conducts data exchanges with other Boeing divisions, other companies, and governmental agencies. The principal file areas maintained by the data center are:

1) Technical reference file

2) Historical information and failure data file

3) Interservice data exchange program (IDEP) file.

The reference material contained in these information files is comprised of many different types of publications, ranging from a single statistical clipping from a periodical to a complete weapon system history. Some items are related to a specific function, while others are very general in their application. The physical characteristics of items also differ, e.g., reports obtained from IDEP are on microfilm; other materials are single data sheets or complete documents.

Utilizing the data and information services provided through the data center, component failure rate estimates, respective sources and the qualifying and limiting factors influencing these estimates were noted. Table 3.4-1 is an example of the variety of information examined and the selected failure rates.

Finally, point estimates of component failure rates were selected for the two mission time periods, 1975 and 1985. The variations in failure rates over the range found for each component type were due to differences in the following factors:

1) Complexity of functions provided and parts within the components.

2) Loading or stress level of the component parts.

3) Inherent reliability growth potential and the assumed date of procurement or use.

The selection of point estimates from this range was made on the basis of analogies to comparable equipment in known systems and judgment relative to the above factors.

In some instances, such as for the pump listed in Table 3.4-1, the failure rate for the two time periods was assumed to be the same. It was considered that such hardware will have reached its reliability maturity prior to use on 1975 missions. In other cases, reliability growth was assumed beyond present hardware. The following are typical examples of the rationale used in selecting point estimates failure rates.

The range of failure rate estimates for an accelerometer was from 10 to 200 per ten million hours. The lowest rate was used by Autonetics Division of NAA for the Voyager Attitude Reference Subsystem Proposal. The highest rate was used in the Boeing Burner II Reliability Analysis Report. A rate of 40 for the 1985 Mars mission was selected based on the assumption that reliability growth by a factor of 3 will be achieved over existing hardware by that time. For the transponder listed in Table 3.4-1, the range of failure rates was approximately 400 to 700. The lower estimate was taken from an analysis used on the Voyager Spacecraft Telecommunication Subsystem Proposal by Philco Radio, while the higher estimate was taken from a Collins Radio Study of the Apollo X Communications and Data Subsystems. It was assumed that the differences among the four estimates shown in Table 10.3-1 were due primarily to differences in basic equipment definition, component part generic failure rate estimates, date of hardware procurement and rate of reliability growth. The value of 300 for the 1975 time period was selected based on the assumptions that the article would be similar to the one proposed for the Voyager spacecraft and would probably have a somewhat lower failure rate since the Voyager estimate was for a proposed 1971 mission. Two estimates were used for the 1985 time period. The lower value of 60 was used for the 1985 Libration Center mission while a higher value of 100 was used for the Mars landing mission based on the assumption of higher performance requirements for the latter mission.

### 3.4.4 CRITERIA FOR IDENTIFYING MAINTENANCE REQUIREMENTS

Maintenance requirements for manned orbital or interplanetary spacecraft are based on: (1) an assumed distribution of failure times; (2) probabilities of failure occurrences; (3) repair/restoration procedures; (4) crew skills available; (5) troubleshooting and failure detection devices; and (6) hardware criticality rating.

The identification of maintenance requirements for the configurations reviewed in this study involved the description of the spacecraft subsystems down to the replaceable component level. An analysis of each of these components resulted in the identification of the equipment requirements, crew skills, repair times, and other maintenance aspects associated with replacement or repair of the item. Because scheduled maintenance can be predicted, and accounted for

Table 3.4-1: TYPICAL FAILURE RATE SOURCE INFORMATION

| Component | Failure Rate Used Failures x $10^{-7}$/hr | | Basis for Failure Rate Selection | |
|---|---|---|---|---|
| | 1975 | 1985 | Failure Rate | Data Source |
| A. Inertial Platform & Electronics | | 700 | $540 \times 10^{-7}$ to $9620 \times 10^{-7}$* | - CA-ID 2588, Vol. II, "Inertial Navigation System for C-5A Military Transport Program," Inertial Division, Sperry Gyroscope Co., January 1965.<br>- T5-512/32, Vol. IIA, "Navigation and Data Processing System for the C-5A Aircraft," Autonetics, North American Aviation, Inc., March 1965.<br>- CE 14090, Vol. II, "C-5A Cargo Aircraft Navigation Subsystems," A.C. Spark Plug, The Electronics Division of GMC, January 1965.<br>- Autonetics Letter, 64 AN/NSD 2506. "Self-Contained Navigation Systems, Boeing Supersonic Transport," May 1964. |
| B. Accelerometer | 150 | 40 | 200 | - Boeing Document D2-82665-1, "Burner II Reliability Analyses Report," January 7, 1966. |
| | | | 100 | - Boeing Document D2-100255, "Reliability Analyses and Supporting Data - Lunar Orbiter," June 17, 1964. |
| | | | 122 | - Lockheed Report SP-380 -64-2, "Reliability Estimate and Analysis Report for Mariner C Vehicles 6931, 6932 (Agena)," May 28, 1964. |
| | | | 10 | - Autonetics Proposal to The Boeing Company for the Voyager Attitude Reference and Autopilot Subsystem, July 5, 1965. |

* Range is given because information from individual sources is either classified or proprietary information.

Table 3.4-1: TYPICAL FAILURE RATE SOURCE INFORMATION (Continued)

| Component | Failure Rate Used Failures x $10^{-7}$/hr | | Basis for Failure Rate Selection | |
|---|---|---|---|---|
| | 1975 | 1985 | Failure Rate | Data Source |
| C. Gyro | 200 | 50 | 100 | - Honeywell Aero. Report R-ED24181, "Proposal for Satellite Injection Guidance System," June 18, 1964. |
| | | | 200 | - Autonetics Division of NAA Proposal to Boeing for the Voyager Attitude Reference and Autopilot Subsystem, July 5, 1965. |
| | | | 400 | - Boeing Document D2-100255, "Reliability Analyses and Supporting Data---Lunar Orbiter," June 17, 1964. |
| | | | 400 | - Lockheed Report SP-3802-64-2, "Reliability Estimate and Analysis Report for Mariner C Vehicles 6931, 6932 (Agena)," May 28, 1964. |
| | | | 50 | - General Electric Co. Report No. 635D4257, "Stabilization and Control Subsystem Orbiting Astronomical Observatory Eighth Quarterly Report" |
| D. Pressure Transducer | 200 | 200 | 500 | - North American Aviation Document SID 64-1-3, "Study of Subsystems Required for a Mars Mission Module," January 2, 1964. |
| | | | 360 | - Boeing estimate for Voyager Spacecraft. |
| | | | 232 | - Beech Aircraft estimate for Apollo. |
| E. Pump, $CO_2$ Transfer of fluid | 200 | 200 | 22.5 | - North American Document SID 65-761-5, "Manned Mars/Venus Flyby Vehicle Systems Study" |
| | | | 1000 | - North American Document SID 64-1-3, "Study of Subsystems Required for a Mars Mission Module" |

Table 3.4-1: TYPICAL FAILURE RATE SOURCE INFORMATION (Continued)

| Component | Failure Rate Used Failures x $10^{-7}$/hr | | Basis for Failure Rate Selection | |
|---|---|---|---|---|
| | 1975 | 1985 | Failure Rate | Data Source |
| E. Pump, $CO_2$ Transfer of fluid (Continued) | | | 200 Range of generic failure rate (22.5-274) | - North American Document SID 64-1860-6, Prepared by AiResearch Manufacturing Division of Garrett, "Extended Apollo Systems Utilization Study" |
| F. Transponder | 300 | 60 100* | 712 | - C-Band Transponder, "Extended Apollo Systems Utilization Study Apollo X Communications and Data Subsystem Study," prepared by Collins Radio Co. |
| | | | 550 | - FARADA Data---Transponder, Radar Beacon, Air Traffic Control Used on Flight Control and Navigation System on 707/720 Aircraft. |
| | | | 440 | - Boeing Lunar Orbiter Reliability Analyses. |
| | | | 396 | - Philco Proposal to Boeing for Voyager Spacecraft Telecommunications Subsystem. |

* Planetary Landing Mission.

in system programming (including the provisioning of on-board resources), the burden of the study was to determine the probable extent and influence of unscheduled maintenance as a factor in mission accomplishment. The functions required to perform the unscheduled maintenance tasks that were considered in the maintenance analysis are described in the following paragraphs.

1) Fault Indication---An initial requirement for unscheduled maintenance normally will develop from display indications or scheduled maintenance inspections. Basic operational data for each system, such as measurement of pressures, temperatures, quantities, guidance and navigation data, position information, and power levels, is presented on display panels for monitoring and control of system operations. Caution and warning lights are used to signal the degradation of those critical system functions that require more immediate attention and corrective action.

2) Fault Isolation and Identification---After a fault indication has been received, the indication will be evaluated and cross-checked with other system instrumentation to verify that the fault indication is valid. This presumes a significant improvement in the state of the art of fault isolation equipment by the time the missions considered in this study are conducted. The available displays will be examined; additional tests will be made, using either built-in capabilities of display consoles or checkout equipment, and, if required, other maintenance test equipment will be used to isolate the malfunction to a replaceable component or specific part of the system. From the fault indication, it will be determined whether the maintenance is to be performed in a shirtsleeve environment or in an unpressurized or exterior area requiring a pressurized spacesuit and backpack operation. A determination also will be made of the maintenance equipment required to correct the malfunction, and of the spares required. The maintenance equipment, including personnel and tool tethering devices, locomotion devices, and spares will be obtained from storage.

3) Pressurization and Locomotion Requirements---If the malfunction is within the normally pressurized area, the maintenance personnel can proceed directly to the fault location. If the malfunction is in an unpressurized area or external to the spacecraft, egress through an airlock in a pressurized spacesuit with a backpack will be required. Crewmen required to work in a pressurized spacesuit must prebreathe pure oxygen for about 30 minutes at the spacecraft's normal internal pressure (7 psia) to avoid bends, before transfer to pure oxygen at the spacesuit pressure of 3.5 psia. For external maintenance a means of maneuvering will be necessary, either through a maneuvering unit or through the use of tethering devices and handholds. Tethering devices will be required for the maintenance equipment and spares for both exterior and interior maintenance.

4) Space Environment Considerations---A space environment factor that could affect the performance and scheduling of extravehicular maintenance is radiation hazard. This is greater at some localities in space than at others. Therefore, it may be necessary to schedule extravehicular activity (EVA) to avoid high radiation portions of an orbit, if the malfunction is such that a delay can be tolerated. Additional space environment factors that must be considered during the development of EVA maintenance

techniques are temperature extremes, micrometeoroids, electrostatic charges, and light intensities.

5) Fault Evaluation---After access has been gained to the area of the malfunction, verification of the fault will be made; additional fault isolation may be required to identify items to be replaced. If at any time it is apparent that a malfunction cannot be corrected, the problem will be coordinated with Earth. If the problem is serious enough, it may require evacuation of the spacecraft and return of personnel to Earth (if possible), or retreat to the reentry vehicle until return is possible. In most cases, an alternate mode of operation can be used until return to Earth or until the next resupply mission, at which time the necessary maintenance equipment or spares can be brought to the spacecraft.

6) Restoration to Normal Operation---Corrective action generally will consist of replacement of the faulty item, although in some cases, such as damage to structure, ducting, and large tanks, the maintenance will involve repair. During maintenance operations, provisions must be made for containing debris and fluids to prevent contamination of the area. This will be true both inside and outside the spacecraft. After the necessary corrective action has been taken, the installation will be inspected, serviced as required, and checked out. Any removed access panels or equipment will be replaced. Personnel, equipment, and the removed item will return to the spacecraft, the maintenance equipment will be returned to storage, and the $O_2$ equipment, spacesuit, or backpacks serviced as required. The removed faulty unit will be inspected for any visual evidence of failure; minor tests with available maintenance equipment may also be conducted. If a small repair shop is available, minor repairs such as cleaning of parts, adjustment, or calibration of instruments, etc., can be performed. The maintenance action taken, including pertinent data and observations, will be logged and the faulty item will be placed in storage for disposal. The maintenance data also will be transmitted to Earth at the next communication period.

## 3.5 STUDY METHODOLOGY

Seven interrelated tasks were identified as basic elements of the study. These were essentially reiterative throughout most of the study period, because the material underwent considerable refinement and adjustment as information was accumulated and analyses progressed. The tasks were sequenced as follows:

Task 1. Select Missions and Spacecraft Configurations

Task 2. Analyze Spacecraft Subsystems

Task 3. Identify Maintenance Requirements

Task 4. Conduct Performance and Cost Trades

Task 5. Identify Maintenance Philosophies

Task 6. Identify Spacecraft Design Criteria

Task 7. Identify Technical Research Requirements

In the following sections each of the tasks is discussed in more detail and the methodology employed in each task identified.

### 3.5.1 SELECTION OF MISSIONS AND SPACECRAFT

Two representative manned long-duration missions were selected for each of the two time periods of interest. These were categorized as Earth-orbital and interplanetary. Principal mission factors were defined and the nature of each mission was identified. Concurrent with analysis and selection of basic missions, associated spacecraft were reviewed to identify the candidate configurations most appropriate to this study. One determining factor in the selection of both mission and spacecraft was the availability of useful data. A large number of references were reviewed during the selection process. References 1 and 2 were found to provide the most comprehensive coverage of the types of missions to be studied, and were used to baseline the missions and spacecraft configurations. Because these references were not the latest available, changes in the baselines were made as required using information derived from the various other references. The process of configuring the spacecrafts necessarily overlapped into Task 2 where spacecraft subsystems were identified and analyzed.

### 3.5.2 SUBSYSTEM ANALYSIS

Subsystems of the selected spacecraft configurations were analyzed so that the criteria necessary to perform subsequent tasks of the study could be identified. A common and logical breakdown of subsystems also was established. These were segregated into modules and components as necessary to establish the maintenance level that would form the basis for identification of the maintenance requirements. Wherever possible, commonality of modules within the same subsystem for each spacecraft concept was established. Baseline subsystems were established for each spacecraft concept for the 1975 time period, and were modified or changed as necessary to approximate the expected state of the art for the 1985 time period. Subsystem variables evaluated included failure rates,

operating times, weight, volume, cost, mean repair time, maximum allowable downtime, repairability factor, and criticality factor.

The useful output of Task 2 was a set of subsystem data sheets for each mission. These sheets organized the subsystem variables into a format that could be punched on computer cards for automated analysis in a future task. The subsystem data sheets (MARCEP data sheets) are reproduced in Volume III. The data point entries made on the MARCEP data sheets are explained below.

1) Nomenclature---The nomenclature describing each component or assembly provides the first entry on the data sheet. In total, this provides an equipment component list, by subsystem, for the entire spacecraft.

2) Subsystem---Each subsystem was assigned a two-letter identification code:

| Subsystem | Code |
|---|---|
| Communications | CM |
| Crew System | CS |
| Data Management | DM |
| Electrical Power | EP |
| Experiment System | EX |
| EVA Equipment | EV |
| Inflight Maintenance Equipment | ME |
| Inflight Test | IF |
| Life Support | LS |
| Navigation and Guidance | NG |
| Planetary Lander | PL |
| Propulsion | PP |
| Reentry | RE |
| Rendezvous and Docking | RD |
| Stability and Control | SC |
| Structure | ST |

3) Component Number---Each component within a given subsystem was assigned an arbitrary number, according to the original sequence when the subsystem listing was established. Once this number was assigned it was inviolable, and never reused if the item subsequently was deleted as a result of further analysis and evaluation. Any item added after the original sequence had been established was given the next unassigned number regardless of its place in the sequence.

4) Quantity in Basic System---Reflects the number of units required to make up a basic, essentially nonredundant, but completely operable subsystem.

5) Operating Failure Rate ($\times 10^7$)---This is the average number of times the component may be expected to fail in 10,000,000 hours of operation.

6) Dormant Failure Rate (x $10^7$)---This is the average number of times a component may be found to be faulty during 10,000,000 nonoperating or on-the-shelf hours.

7) Weight in Kilograms---Weight per unit of the line item.

8) Volume in Cubic cm---Volume per unit of the line item.

9) Mean Repair Time---Time in hours adjudged to be the average required to restore the item to its original operating condition after a failure has occurred.* A very serious effort was made to be realistic in this figure, taking into account the space environment, special conditions if appropriate, kinds of tools and other resources required, and inherent difficulty of the function.

10) Repairability Code---Each item was evaluated for its susceptibility to repair, which was introduced into the computer program for determining relative merits of sparing or making redundant. Codes used were as follows:

    1. Item cannot be spared or made redundant.
    2. Item cannot be repaired or replaced in orbit.
    3. Repair requires external work in spacesuit.
    4. Repair is difficult---poor access or other factor.
    5. Repair is easily performed---shirtsleeve environment.

11) Criticality Code (CC)---Each item also was evaluated for the influence it had on the system in the event of a fault. Codes used were:

    1. Safety critical---item must operate continuously.
    2. Downtime critical---redundancy required.
    3. Downtime critical---repair in maximum downtime or less.
    4. Repair can be deferred up to 7 days (except RC-2 or RC-3).
    5. Repair can be deferred indefinitely (item is considered for mission success only).
    6. Spares only.

12) Maximum Allowable Downtime---This was the maximum elapsed time in hours that could safely be tolerated between a failure and restoration of the system or equipment to an operating condition.

13) First Supplementary Component Number---The entry in this column is a separate computer code number for an additional switch, valve, indicator, sensing or monitoring device, or other part required when the line item is added in as standby redundant. Weights, volumes, reliabilities, etc., of these units are mitigating factors to be applied when the line item is used in that manner.

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* Also termed "mean-time-to-repair" (MTTR) in analytical discussions.

14) Second Supplementary Component Number---An additional entry to be used as above when a second such component is required. This may or may not be the same as the first component.

15) Percent Operating Time (x 10)---The proportion of a mission during which the line item is anticipated to be working. Multiplying by ten permits computer mechanization of items with low operating times.

16) Parallel Lockout---Denies consideration of the line item as a parallel redundant unit. Applies particularly to components associated with EVA, experiments, structure, ducts, and other items for which it is not practicable to provide parallel redundancy.

It is apparent from the nature of some of the data points that this task overlaps Task 3. In practice, portions of Task 2 and Task 3 were accomplished concurrently.

### 3.5.3 IDENTIFICATION OF MAINTENANCE REQUIREMENTS

After selected spacecraft systems and components were identified, anticipated scheduled and unscheduled maintenance activities were determined. Design and operational requirements dictated by these maintenance activities also were defined. The analysis included identification of scheduled maintenance items, determination of Degree "2" replaceable items and their failure frequency, and identification of any "unreasonable" activities, which then were used in developing suggested design criteria and potential areas of further research. During the analysis, specific attention was directed to such factors as effects of local environment, tools, automated fault determination and testing, extravehicular maintenance requirements, special skills, spares provisioning, and maintenance data.

Worksheets were prepared in analyzing each of the four selected configurations for the maintenance tasks to be performed by the crew. These sheets display the maintenance factors such as crew skill, task times, tools, data, etc., that influence or are affected by the equipment being analyzed. The visibility they provide gives opportunity for comparing effects of progressive technical development, as well as defining major aspects of hardware design, crew factors, and general logistics considerations involved with the various maintenance tasks.

The worksheets, which are reproduced in Volume III, are grouped by spacecraft configuration for a given mission. Within this group each configuration is subdivided by subsystem, which in turn is broken down into its maintenance-significant components. The component list so identified is the same as that used in the computer optimization program (see the MARCEP data sheets). Each of the major assemblies or components of the subsystem is analyzed with respect to requiring repair, replacement, or servicing (and servicing frequency). In some instances a more detailed description of the maintenance functions is included for clarity. Each maintenance function has listed with it the anticipated number and type of skill required to perform the maintenance task. The mean time required to perform the task and the average metabolic rate of the crewman performing the task are estimated and listed. Where applicable, an

indication of the special tools required to perform the maintenance task is shown. To conserve space on the worksheet, these are listed by numbers that are referenced to the inflight maintenance equipment list in the subsystem description for the respective configuration, given in Volume III. Useful maintenance data aids are listed on the worksheets and checked as deemed appropriate. The component location and the associated environmental factors are also listed and checked as appropriate to the maintenance task. A column is included for any additional requirements or remarks pertaining to the maintenance function.

One of the principal uses of the worksheet data is to give visibility to the design engineer as to various considerations he must take into account during the design of his hardware. For example, the designer may need to consider that his component should be maintainable by only one crewman, using one primary skill. He must consider the crewman to be limited in his metabolic workload, particularly if the component repair requires EVA. He must ensure that the necessary tools required for the maintenance task are available. He should consider which maintenance aids will be most useful in maintaining the component he is designing. The ease of maintenance must be considered in relation to the component location in the vehicle, the workspace around the component, the effect of zero-g, cabin pressure required, radiation hazards that must be attenuated, lighting requirements, maneuvering necessary, restraint required, and whether the task must be performed EV.

The maintenance task analysis worksheets will aid in determining reasonable crew performance requirements. Whereas crew size is relatively independent of maintenance requirements with respect to the time loads involved, maintenance tasks, skills, and related training are dependent on the maintainability aspects of the component design. Time allowances and EVA considerations are important factors from the standpoint of the crew physical limitations. For example, if a component is designed to be accessible only under EV conditions, it must be easily repaired or replaced to minimize the frequency duration of EVA required and to compensate for the degradation in restraint, mobility, and dexterity associated with spacesuit tasks.

Logistics considerations also may be obtained from the worksheets. The quantities of expendables associated with EVA are directly dependent on the frequency and duration of the EVA. The expendables may be summarized from the worksheets. In addition, system trades may be performed on the basis of worksheet information. For example, the scheduled maintenance average man-minutes/day breakdown by skill type, as shown in Sections 5.2 and 6.2, is extremely helpful in determining crew composition and training requirements.

### 3.5.4 CONDUCTING PERFORMANCE AND COST TRADES

The first step in the performance and "cost"* analysis part of the study was performed with a computer programmed mathematical model called MARCEP (maintainability and reliability cost effectiveness program). With a

* "Cost" or "costs" refer to the penalty or penalties incurred by the use of a component, i.e., weight, volume, and repair time.

single-thread system provided, MARCEP first determines the reliability of each component and then the basic system reliability. Each item is then considered for addition to the system. Up to three ways of addition are considered; the possible methods being determined by repairability and criticality codes used to describe the component as part of the basic system. The three methods of addition are: (1) parallel redundancy; (2) standby redundancy; and (3) spares redundancy. The program uses Fortran IV language that is operated on by the Univac 1108 digital computer.

For each component, parametric evaluation and selection of the best method of addition are conducted, and the parametric value stored in tabular array. The parametric value stored in this study was change in reliability per weighted change of component weight. The change is due to the trial addition of the component to the system. When parametric values have been stored for each component, the entire array is searched to select the largest value. The component responsible for this value is then added to the system.

As a component is added to the system, a new parametric value is determined for it, and the new value is entered in the tabular array. Each time a component is added to the system, it is added in the most advantageous form of redundancy allowed. This iterative process can proceed ad infinitum, but practical or required constraints are applied to terminate the process. A more detailed technical discussion of the MARCEP processes is available in Reference 88.

The useful result of the program is a printed sheet of the components added to the system, in their sequence of addition, with new system reliability, method of addition, and cumulative system "cost" parameters shown. The inherent flexibility of the MARCEP model made it possible to perform a number of parametric sensitivity studies with relative ease. Among the sensitivities evaluated were: weight and volume of spares and redundancies to mission duration; weight and volume of spares and redundancies to repair confidence level and mission duration; and weight and volume of spares and redundancies to gross errors in estimated mean repair times. Results of the above sensitivity studies are presented in Sections 5.1 and 6.1. Trial investigations showed that gross errors in component weights and failure rates could be evaluated easily by other means, and investigation of these sensitivities was not continued further. As explained in Section 5.1.1, errors in overall failure rate could be evaluated by changing the mission duration (look at half the mission time to evaluate half the failure rate). It was also found that a gross component weight error would affect the added weight of spares and redundancies by the same factor.

Additional studies into the effects of selecting a Degree "0" maintenance concept were made by reidentifying component repairability and criticality codes for the 1975 Mars flyby mission, and making analyses at both the system and subsystem levels.

Far more detailed information was available in the mass of computer outputs than could possibly be handled within the time and budget limitations of this contract; maximum effort was addressed to the extraction of meaningful information in fulfillment of specific study objectives, with the realization that at least an equal effort could have been devoted to more depth of detail in the

review of specific subsystems, or to further analyses of contending maintenance concepts.

The second step in the task was to simulate the operation of the mission under real-time conditions. The mission simulation model was designed to simulate the unscheduled maintenance requirements of a fully configured spacecraft as developed by MARCEP to the desired level of assurance, and to determine the effects of maintenance time, spares weight, resupply intervals or mission duration, system reliability, and maintenance resources on the system. The simulation method uses the IBM general-purpose system simulation (GPSS) Model III language that is operated on by the IBM 7094 digital computer. This GPSS program has been used by the contractor on a number of other contracts and studies. Two applications are documented in References 67 and 68.

The initial step towards development of this simulation model was to portray the activities involved with unscheduled maintenance in a functional sequence diagram. This is then translated into a decision logic network that in turn can be readily transcribed into the GPSS language.

Figures 3.5-1 and 3.5-2 provide a simplified version of the decision logic network used in this simulation, which is given here to illustrate the general procedure used in the simulation. The first block labeled "Create Random Failures" caused unscheduled failures to occur randomly within an assumed exponential distribution about the total system mean-time-between-failure (MTBF) rate. A separate small Fortran program was used to calculate the total system MTBF, including any parallel or standby components added to the basic system by the MARCEP, and the contribution that each of the over 500 component types made to the total system MTBF. Each time a failure was created, random numbers were generated to identify the subsystem and the component of that subsystem that failed. The probability that the failure was within a specific subsystem was directly proportional to: (1) the ratio of the subsystem failure rate to the total spacecraft failure rate; and (2) the ratio of the component failure rate to its subsystem failure rate. After the failed component had been determined, its number, weight, and volume were tabulated within the computer. Next the resources (crew skills, maintenance equipment, locomotion aids, etc.) required to perform the maintenance task were identified. A check was then made to determine if the resources required were available. The types of resources and the numbers of each resource previously had been inserted into the computer. This resource quantity could be unlimited, or restricted, as desired to determine the effects of queuing. In this study unlimited quantities were assumed at first to determine maximum usage. From this it was decided to provide two of the basic maintenance tool kits and one of each other resource. Further simulations based on the resources thus limited resulted in some queuing, but it was not significant enough to warrant providing additional quantities of the resources.

If all of the resources were not available, then it was necessary to wait until an existing maintenance task was completed and the desired resource was again available. The time that was spent waiting for a resource was recorded. Once it had been determined that all the resources were available, the maintenance time that must be spent on the task was calculated. Initially the

mean-time-to-repair (MTTR) for each component type, as determined in the maintenance task analyses (see Volume III), were fed into the computer. However, in reality it is known that the actual repair times may actually vary considerably about the mean value. Therefore, the MTTR values entered into the program were multiplied by a number randomly picked from a log normal cumulative distribution curve. This resulted in the actual repair time varying from 0.1 to 10.0 times the expected MTTR. This calculated maintenance time was then used as the time that the maintenance resources were applied to the task. If more than one man was required for the task, the time was multiplied accordingly. The data on maintenance time and the use of the resources were then recorded. A check was then made as to whether the maintenance task involved EVA. If EVA was required the number of airlock uses were recorded, based on one airlock use (one-use is one complete cycle of egress and ingress through the airlock) for every 3 hours or fraction thereof of maintenance time. The manhours of spacesuit use were also recorded, based on two men being required for all tasks that required EVA. The resources used on the maintenance task were then returned to storage so they would be available for the next task. After each day of simulation, statistics were tabulated on the spares weight used, spares volume used, number of airlock uses, and the manhours of spacesuit use required. The computer storages where these values were accumulated were then reset to zero. The simulation was then continued until this cycle had been repeated 100 times. The statistics for the total simulation of 100 cycles of the selected mission duration or resupply interval were then tabulated.

### 3.5.5 IDENTIFYING MAINTENANCE PHILOSOPHIES, SPACECRAFT DESIGN CRITERIA, AND TECHNICAL RESEARCH REQUIREMENTS

The final three tasks of the study were found to be so interdependent that they must of necessity be discussed as a group. The actual accomplishment of these three tasks did not evolve as a separate step that started after Task 4 was completed. Bits of information were filed under these task headings throughout the study for evaluation after completion of Task 4. It was in this manner that feedback from problems identified in earlier tasks was used.

Maintenance philosophies were derived for each of the mission types analyzed during the study. The combination of maintenance tasks, crew number and skills, maintenance aids and equipment, spares, resupply, and spacecraft design were considered to the end that the best and most efficient combination could be determined. An associated requirement was the determination of a proper selection criterion on which a good maintenance philosophy could be based. Also, specific design criteria, to be applied to spacecraft programs of the future, that would most effectively improve system maintainability were identified for recommendation. The analysis of spacecraft subsystems and the identification of maintenance requirements served to establish those tasks or items of equipment that:

1) Required the most maintenance time;

2) Caused the most maintenance actions;

3) Were the most critical to spacecraft operation.

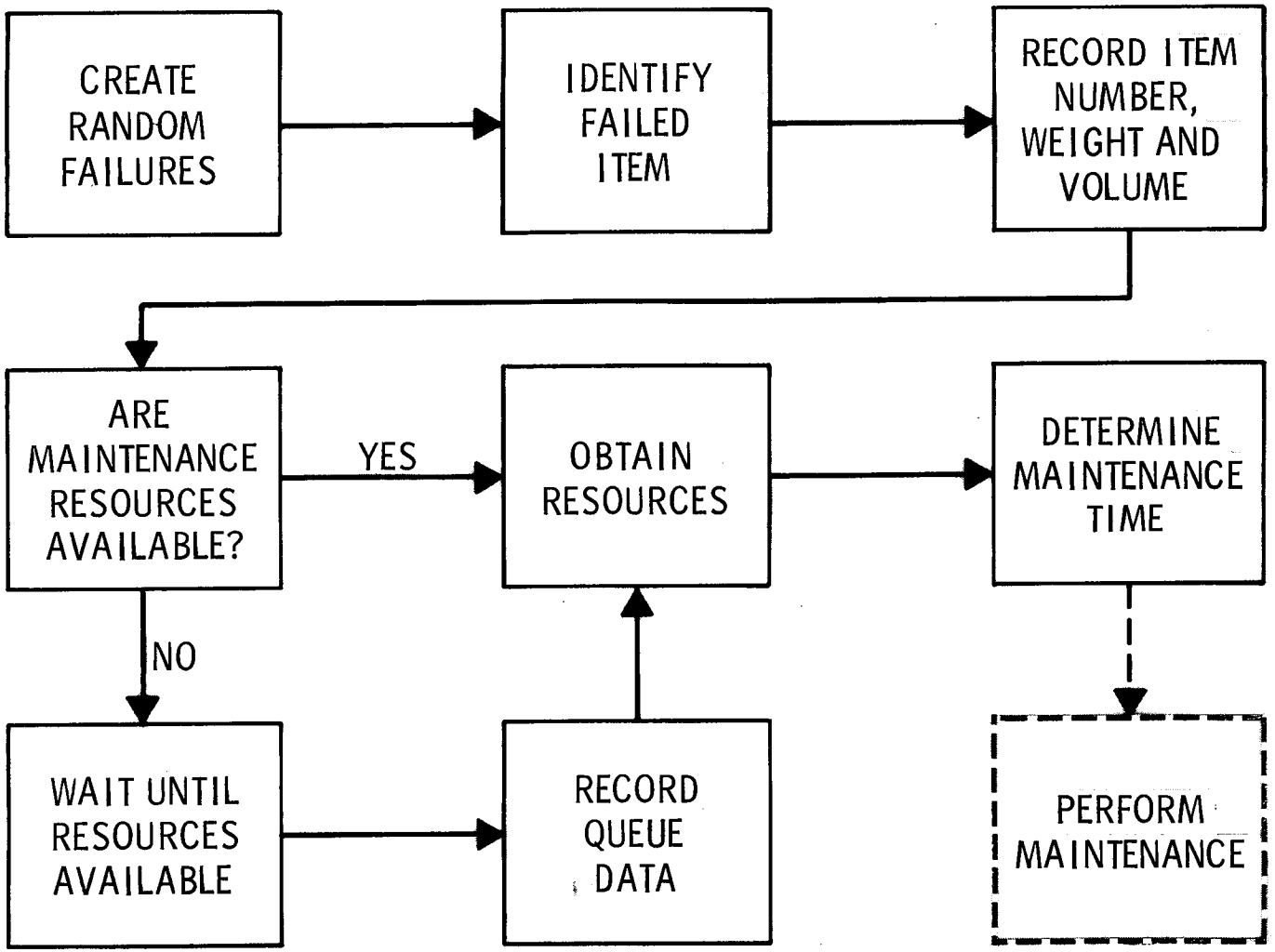


Figure 3.5-1: MISSION SIMULATION SIMPLIFIED LOGIC NETWORK — Sheet 1

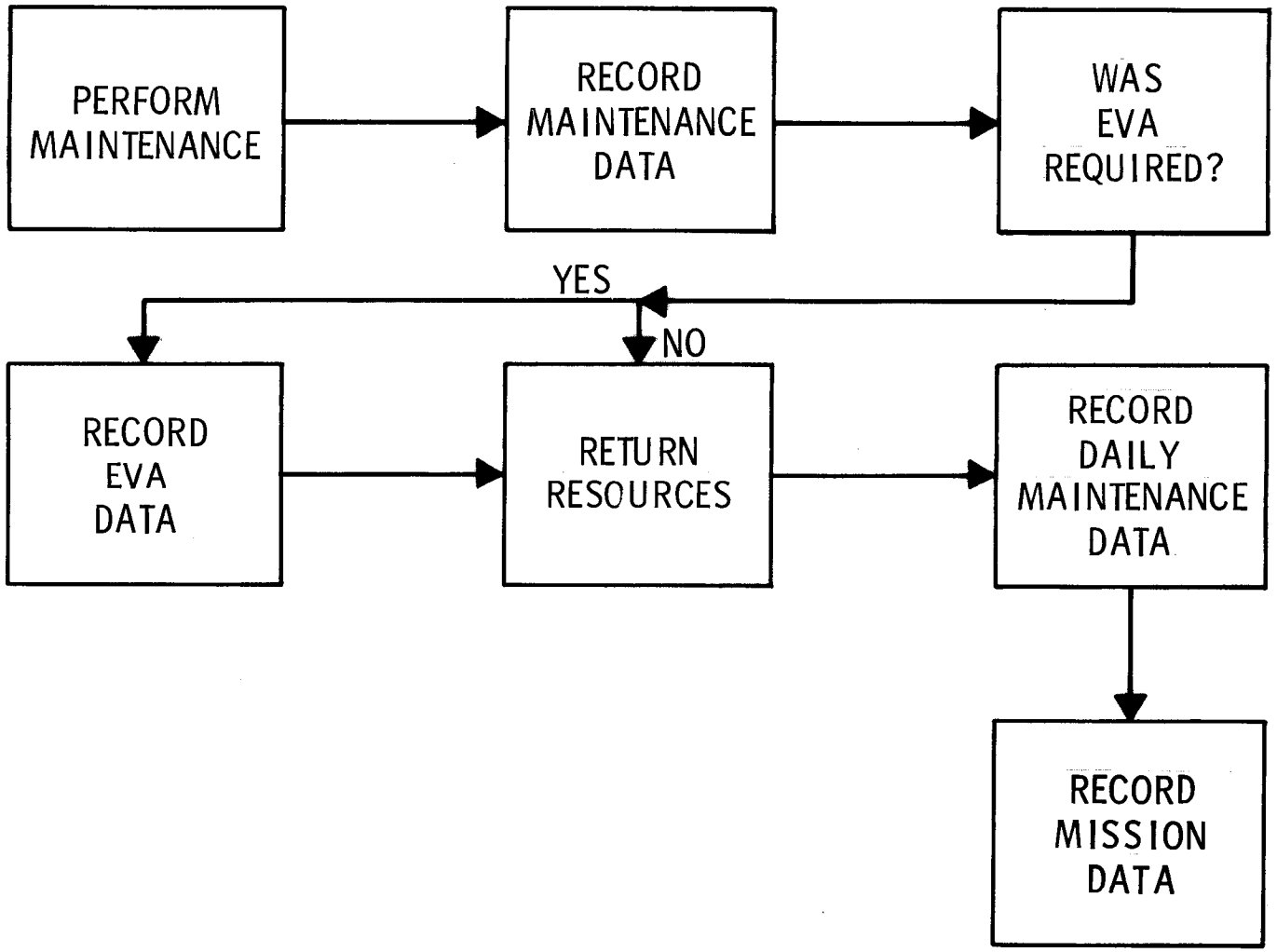


Figure 3.5-2: MISSION SIMULATION SIMPLIFIED LOGIC NETWORK — Sheet 2

Finally, areas of technological research needed to acquire the maintainability desired for the 1975 and 1985 time periods were identified for recommended study. Development risks in terms of cost, program delays, and hazardous conditions also were identified where proposed solutions to the problem areas being researched could incur such adverse effects.

# 4.0 MAINTENANCE CONCEPT COMPARISONS

The baseline maintenance concept used for the four study missions was primarily Degree "2," with deviations to Degrees "0," "1," and "3" for specific items that did not lend themselves to Degree "2" maintenance. It was felt that this approach would yield a first approximation to the optimum maintenance concept. To substantiate this, a Degree "0" maintenance concept was generated for the 1975 Mars/Venus flyby mission and evaluated. The required probabilities of assurance for the Degree "0" maintenance concept are achieved in almost all cases by using built-in parallel and standby redundancies instead of spares. Therefore, essentially no unscheduled maintenance is required to correct component failures. It should be noted that the Degree "0" concept does not apply to scheduled maintenance activities, because it was found to be impractical to eliminate this maintenance. Fixed redundancies for some components (such as structure, ducting, etc.) was found to be illogical within the constraints of the mathematical model used for optimization. Therefore, the Degree "0" concept does include some spares and maintenance kits for selected items; but for most components, fixed parallel or standby redundancies were allowed with relatively low penalties for automatic switching. Similarly, for the Degree "2" concept, due to various criticality factors it is illogical to spare every component that might fail, and therefore a small amount of fixed redundancies, together with automatic switching when required, are included in the added weight for the Degree "2" concept when manual restoration appears unfeasible.

The effects of Degree "0" and Degree "2" maintenance concepts were also evaluated at the subsystem level. Again, this comparison was made for the 1975 Mars/Venus flyby mission only; however, the trends found are considered representative of other missions as well. The detailed maintenance concept comparison by subsystem is found in the appendix to this volume.

## 4.1 WEIGHT COMPARISON OF MAINTENANCE CONCEPTS

The first comparison of the Degree "0" and the Degree "2" maintenance concepts was made at the total spacecraft level. Comparison at this level showed that less weight was added under a Degree "2" concept to achieve 99% assurance of crew survival and 99% assurance of mission success than was added for the Degree "0" concept. However, the weight added to achieve mission success for the Degree "0" concept appeared completely unreasonable. This resulted from including backup probes for the experiments subsystem. The number of probes carried to achieve 99% assurance of success was excessive even though the probability improvement was calculated by a spares formula. Results of the comparison are shown in Figure 4.1-1. The broken line curve labeled "B" shows the excessive weight of probes added to achieve 99% assurance of success. Because this approach was unfairly biased, the maintenance concept for the experiment subsystem was redefined. Increments of parallel redundancy were allowed to be added to the probe internal mechanisms and to the on-board experiment packages. The weight increments were small in comparison to the basic weight of the probes and experiment packages; however, the probability increase gained by one increment addition to a probe was equivalent to that gained by launching two duplicate probes to accomplish one mission. This result was considered optimistic,

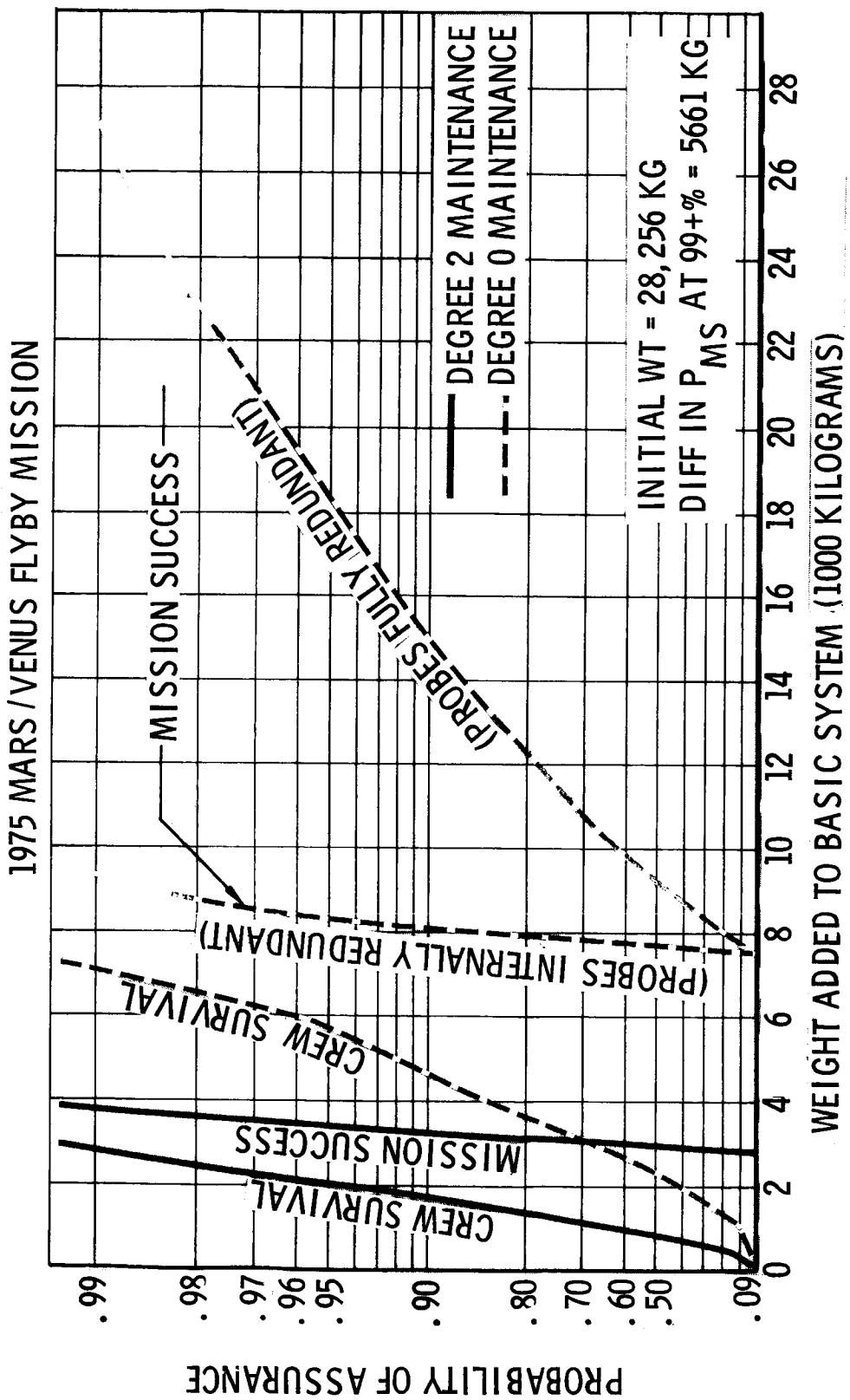


Figure 4.1-1: MAINTENANCE CONCEPT COMPARISON — Total Spacecraft Added Weight vs Probability of Assurance

but certainly fair, for the comparison. The results of the redefined Degree "0" concept are shown as broken line curve "A" in Figure 4.1-1.

As expected, the Degree "2" maintenance concept showed significantly less weight added to achieve a 99% assurance of mission success. The numerical weight difference between the two concepts was over 5600 kg at the 99% mission success points.

## 4.2 COST COMPARISON OF MAINTENANCE CONCEPTS

For mission planning purposes, one of the principal factors in selection of a maintenance concept will be dollar cost, assuming achievement of the same assurance level. To determine the cost impact of the Degree "0" and the Degree "2" maintenance concepts, a relative cost comparison was made. The final configurations of the spacecraft under each of the maintenance concepts were inputs to the costing effort, along with assessments of requirements for additional design, crew training, technical data development, automated fault isolation and numerous other factors affected by the maintenance concept. The summary of the costing is shown in Table 4.1-2. The equivalent dollar cost associated with the 1.000 relative cost shown for the Degree "2" concept is 3,198 million dollars. The assumptions made in the costing as well as the factors eliminated from the costing are indicated in Sections 9.1 and 9.4. Other costing information for specific missions is provided in the subsystems descriptions given in Volume III. It is evident from examination of the costing table that the Degree "2" maintenance concept is desirable from a cost viewpoint as well as from a weight viewpoint. It should be noted that a relative cost factor of 0.001 is roughly equivalent to 3.2 million dollars and the total difference of 0.149 between the two concepts represents approximately $477,000,000. This figure does not include ancillary increases such as booster requirements to accommodate the additional weight incurred by the Degree "0" concept.

Table 4.1-2: COMPARISON OF RELATIVE COSTS FOR DEGREE "0" AND "2" MAINTENANCE---1975 MARS/VENUS FLYBY MISSION

| | Degree "0" Maintenance Concept | | | | Degree "2" Maintenance Concept | | | |
|---|---|---|---|---|---|---|---|---|
| | Dev. | Hdwe. | Op'n. | Total | Dev. | Hdwe. | Op'n. | Total |
| Subsystems | | | | | | | | |
| Life Support | 0.172 | 0.006 | | 0.178 | 0.148 | 0.004 | | 0.152 |
| Communications | 0.230 | 0.005 | | 0.235 | 0.198 | 0.004 | | 0.202 |
| Crew System | 0.019 | 0.002 | | 0.021 | 0.017 | 0.001 | | 0.018 |
| Data Management | 0.040 | 0.010 | | 0.050 | 0.035 | 0.005 | | 0.040 |
| Electrical Power | 0.050 | 0.007 | | 0.057 | 0.043 | 0.004 | | 0.047 |
| Extravehicular Activity | 0.043 | 0.005 | | 0.048 | 0.037 | 0.002 | | 0.039 |
| Inflight Test | 0.002 | Negligible | | 0.002 | 0.001 | Negligible | | 0.001 |
| Maintenance Equipment | 0.001 | Negligible | | 0.001 | 0.001 | Negligible | | 0.001 |
| Propulsion | 0.136 | 0.004 | | 0.140 | 0.117 | 0.003 | | 0.120 |
| Navigation & Guidance | 0.038 | 0.008 | | 0.046 | 0.032 | 0.008 | | 0.040 |
| Stability & Control | 0.022 | 0.007 | | 0.029 | 0.019 | 0.006 | | 0.025 |
| Structure | 0.087 | 0.008 | | 0.095 | 0.075 | 0.008 | | 0.083 |
| AGE | 0.101 | | 0.005 | 0.106 | 0.087 | | 0.004 | 0.091 |
| Test and Demonstration | 0.097 | | | 0.097 | 0.097 | | | 0.097 |
| Software | | | | | | | | |
| Computer Programming | Negligible | | Negligible | Negligible | Negligible | | Negligible | Negligible |
| Training Equipment | 0.002 | | Negligible | 0.002 | 0.002 | | Negligible | 0.002 |
| Simulation Equipment | 0.003 | | Negligible | 0.003 | 0.003 | | Negligible | 0.003 |
| Training | Negligible | | Negligible | Negligible | Negligible | | Negligible | Negligible |
| Technical Data | Negligible | | Negligible | Negligible | Negligible | | Negligible | Negligible |
| Launch Site Support | 0.037 | | 0.002 | 0.039 | 0.037 | | 0.002 | 0.039 |
| Total | 1.080 | 0.062 | 0.007 | 1.149 | 0.949 | 0.045 | 0.006 | 1.000 |

# 5.0 EFFECTS OF MISSION PARAMETERS AND MAINTENANCE ON REPRESENTATIVE EARTH-ORBITAL MISSIONS

A number of different missions, described in other studies, were evaluated for mission concepts, goals, operational characteristics, personnel and hardware requirements, and depth of detailed information, to establish representative and workable baseline missions that could be analyzed in this study. Volume III of this report presents a detailed discussion of the missions selected, spacecraft configuration analyses and selections, and the spacecraft subsystem analyses. It is necessary to review this information and examine the MARCEP data sheets and maintenance task analysis sheets (also contained in Volume III) to fully appreciate the depth of data used as a background for the study analyses.

At the system level, the effect of varying major mission/system parameters was investigated. These parameters included mission duration (resupply period in the case of Earth-orbital missions), weight, volume, mean repair time, and required level of repair confidence. In evaluating the effects of the mean repair time, gross errors in the estimation of repair times were assumed and applied as factors to the baseline repair times. The results of investigating the system-level effects of parametric variations are presented under Section 5.1 for the Earth-orbital class of missions.

Scheduled maintenance activity will have an effect on mission requirements. In particular, scheduled maintenance will affect crew workload and the weight of expendables required to conduct the mission. These aspects of scheduled maintenance are discussed in Section 5.2.

The effects of unscheduled maintenance on overall mission requirements were evaluated by conducting a series of simulations where the mission was examined under simulated real-time conditions. In the simulations, failures were allowed to occur randomly and statistics were recorded on queuing, resource expenditures, and maintenance time (also determined randomly). The results of these investigations are presented in Section 5.3.

As a result of evaluating the effects of various parameters on the mission requirements, it was possible to make preliminary estimates of spacecraft weight and launch payload requirements for each mission. Table 5.0-1 presents a launch weight summary for the 1975 near-Earth orbital mission. Table 5.0-2 presents a launch weight summary for the 1985 $L_1$ Libration Center mission. These launch requirements are discussed in more detail in Volume III.

## 5.1 EFFECTS OF VARYING SELECTED MISSION/SYSTEM PARAMETERS

All baseline spacecraft configurations (see the MARCEP data sheets contained in Volume III for identification of components) were analyzed with the mathematical optimization program to determine the spacecraft system and mission sensitivity to maintainability-related parameters such as weight, volume, cost, reliability, MTTR, MTBF, resupply rate, mission duration, and spares requirements. The mechanics of how this was done have been explained

Table 5.0-1: 1975 NEAR-EARTH ORBITAL MISSION LAUNCH SUMMARY

| | | |
|---|---|---|
| **First Launch---Unmanned Spacecraft** | | |
| Spacecraft (dry weight) | | 15,544 |
| Expendables (propellants, $O_2$, $N_2$) | | 1,615 |
| | Total | 17,159 kg |
| **Second Launch---Initial Manning of Spacecraft** | | |
| 8-Man Stretched Apollo Reentry System | | 7,904 |
| 8-Man Crew (200 lb each) | | 1,130 |
| Cargo Module | | 4,030 |
| Expendables (food, clothing, LSS supplies)** | | 1,084 |
| EVA-Powered Locomotion Units | | 284 |
| Spares Weight (0.99 $P_{MS}$ - 120 days)** | | 1,747 |
| Basic Experiment Requirements* | | 2,500 |
| | Total | 17,679 kg |
| **Subsequent Launches---90-Day Resupply** | | |
| Reentry System | | 7,904 |
| Crew | | 1,130 |
| Cargo Module | | 4,030 |
| Expendables (all requirements including experiment supplies) | | 3,972 |
| Spares Weight (range 5 to 265 kg) | | 265 |
| | Total | 17,301 kg |
| Basic Experiment Requirements* | | 2,500 |
| | Total | 19,801 kg |

* About 10,000 kg are required for the basic experiment program. It was assumed that 25% of this is carried on each of the second through the fifth launches.

** Initial expendables and spares are provided for 90 plus 30 days reserve supply.

Table 5.0-2: 1985 $L_1$ LIBRATION CENTER MISSION LAUNCH SUMMARY

| | | |
|---|---|---|
| **First Launch---Unmanned Spacecraft** | | |
| Spacecraft (dry weight) | | 15,676 |
| Expendables (propellants, $O_2$, $N_2$) | | 4,581 |
| | Total | -20,257 kg |
| Launch Capability | | +36,700 |
| Radiation Shielding Allowance | | +15,443 kg |
| **Second and Third Launches---Initial Manning of Spacecraft** | | |
| Reentry System (8-man Apollo and service module) | | 10,180 |
| Crew (6 men in each launch) | | 848 |
| Cargo Module | | 4,030 |
| Expendables (food, clothing, LSS supplies)* | | 1,763 |
| EVA-Powered Locomotion Devices | | 142 |
| Spares Weight (0.99 $P_{MS}$ - 240 days)* | | 815 |
| Basic Experiment Requirements** | | 3,750 |
| | Total | 21,528 |
| **Subsequent Launches---180-Day Resupply** | | |
| Reentry System | | 10,180 |
| Crew (8 men) | | 1,130 |
| Cargo Module | | 4,030 |
| Expendables (all requirements including experiment supplies) | | 11,148 |
| Spares Resupply (range 10 to 120 kg) | | 120 |
| | Total | 26,608 |
| Basic Experiment Requirements** | | 3,750 |
| | Total | 30,358 |

* Total quantity required for spacecraft for 240 days (180 plus 60 days reserve) is divided between these two launches.

** About 15,000 kg are required for the basic equipment program. It was assumed that 25% of this is carried on each of the second through the fifth launches.

in Section 3.5. Sections 5.1.1 and 5.1.2 discuss the results of these trades and analyses.

### 5.1.1 NEAR-EARTH ORBITAL MISSION

Figure 5.1-1 shows the weight that must be added to the baseline 1975 near-Earth orbital spacecraft to achieve desired mission probabilities of assurance for a number of different resupply intervals (mission times). The curves shown in this figure have been plotted on an inverted log scale so that the higher reliability values could be more accurately plotted. Some significant data for the 90-day interval shows 1071 kilograms added weight for 99% probability of crew survival ($P_{CS}$), and 1630 kilograms for 99% probability of mission success ($P_{MS}$). For 180 days, 1387 kilograms of weight were added for 99% $P_{CS}$ and 2056 kilograms for 99% $P_{MS}$. In both cases, the increased weight in going from 99% $P_{CS}$ to 99% $P_{MS}$ was about 50%. Only a 27% increase in weight for mission success was required to double the mission time, i.e., 90 to 180 days. A 30% increase resulted from doubling the mission time from 180 to 360 days. Of the total added weight for 99% assurance of mission success, 166 kilograms are for parallel and standy redundancy for 30 through 360-day mission times. The remaining weight is for spares. At 540 days, the weight for parallel and standby redundancy increased to 296 kilograms.

Figures 5.1-2 and 5.1-3 illustrate the effects of varying some of the baseline system parameters. Figure 5.1-2 depicts the changes in added weight required for 99% assurance of mission success when varying the confidence level desired in repair of items within the item mean-time-between-failures (MTBF), allowable downtime, or a combination of these factors. PR-4 items were assigned a higher confidence level because these are mission safety critical items. As the required confidence level was increased, it was necessary for more items to be added as parallel redundant to ensure the desired confidence level; therefore, the added weight increased correspondingly. The baseline system was assigned a confidence level of 0.99 for PR-4, which seemed to be a reasonable value and was compatible with the overall probabilities of desired mission success. Note that there was no significant advantage gained from using a lower confidence level for repair, whereas the added weight increased markedly as the confidence level increased.

Figure 5.1-3 shows the changes in added weight resulting from varying the baseline mean-time-to-repair (MTTR). One of the entries in the MARCEP form was an MTTR value for each component. To derive the data presented in this chart, the computer first multiplied each of the component MTTR's by the factor shown before it started its selection process for adding parallel or standby redundancies and spares to the basic system. Again, note that decreasing the MTTR did not significantly affect the weight added. However, large weight increases were obtained when the MTTR values were increased. Actually, in this study it was felt that the MTTR value assigned to each component was generally on the pessimistic (or high) side. This meant that a higher confidence could be placed in the accuracy of the results than if the MTTR values were considered to be optimistic.

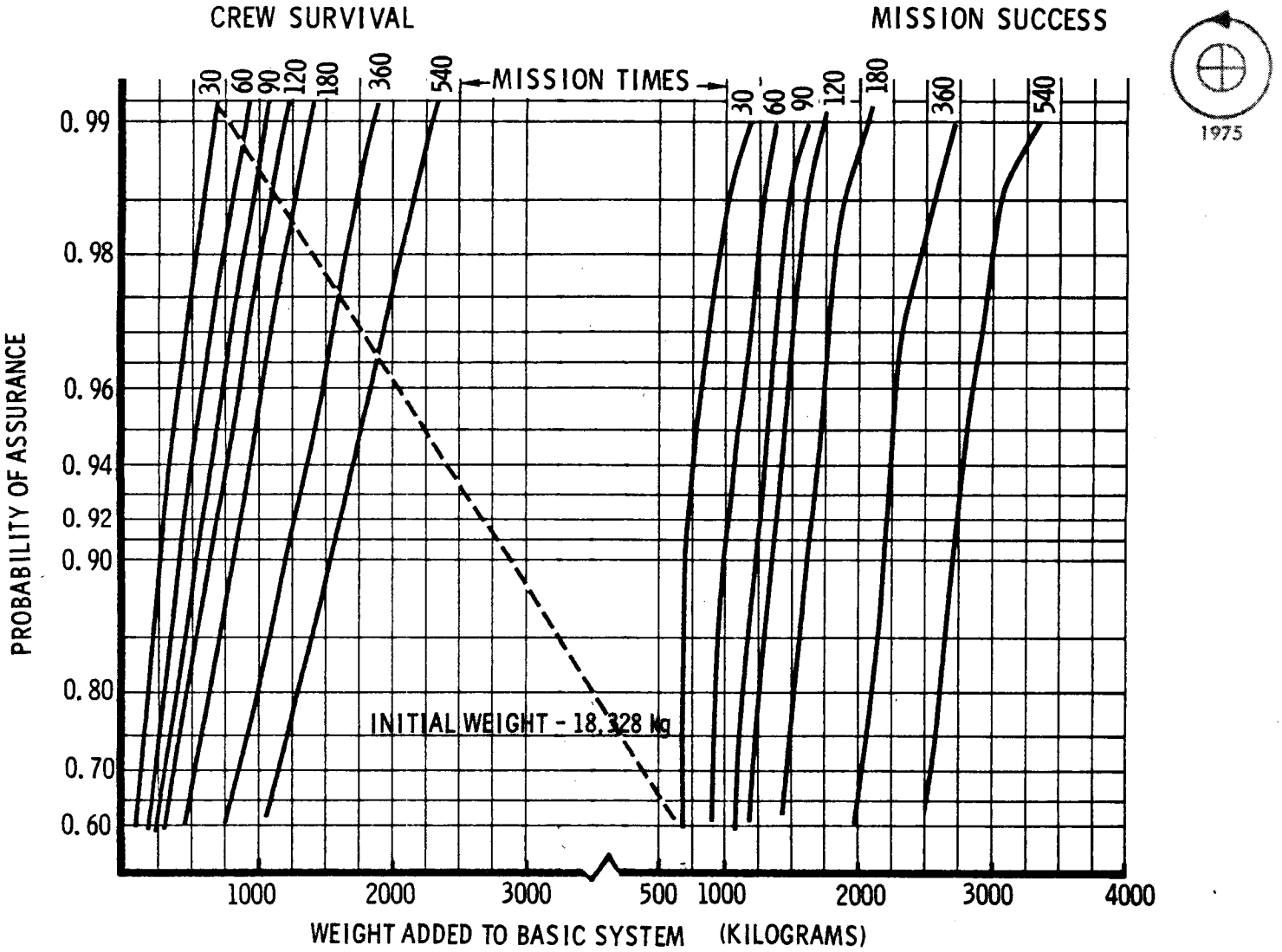


Figure 5.1-1: ADDITIONAL WEIGHT REQUIRED TO ACHIEVE PROBABILITY OF ASSURANCE — 1975 Near-Earth Orbit Mission

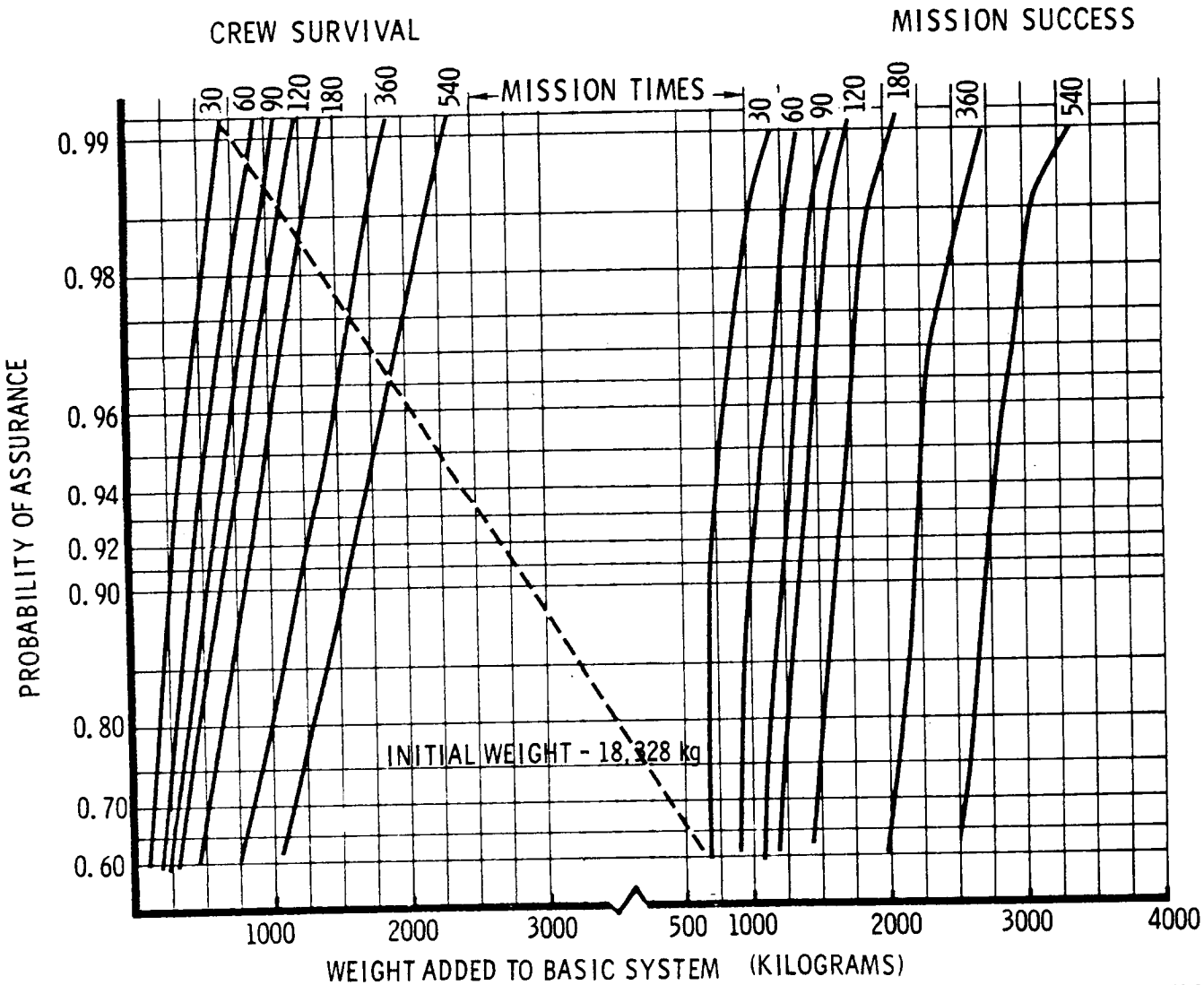


Figure 5.1-1: ADDITIONAL WEIGHT REQUIRED TO ACHIEVE PROBABILITY OF ASSURANCE — 1975 Near-Earth Orbit Mission

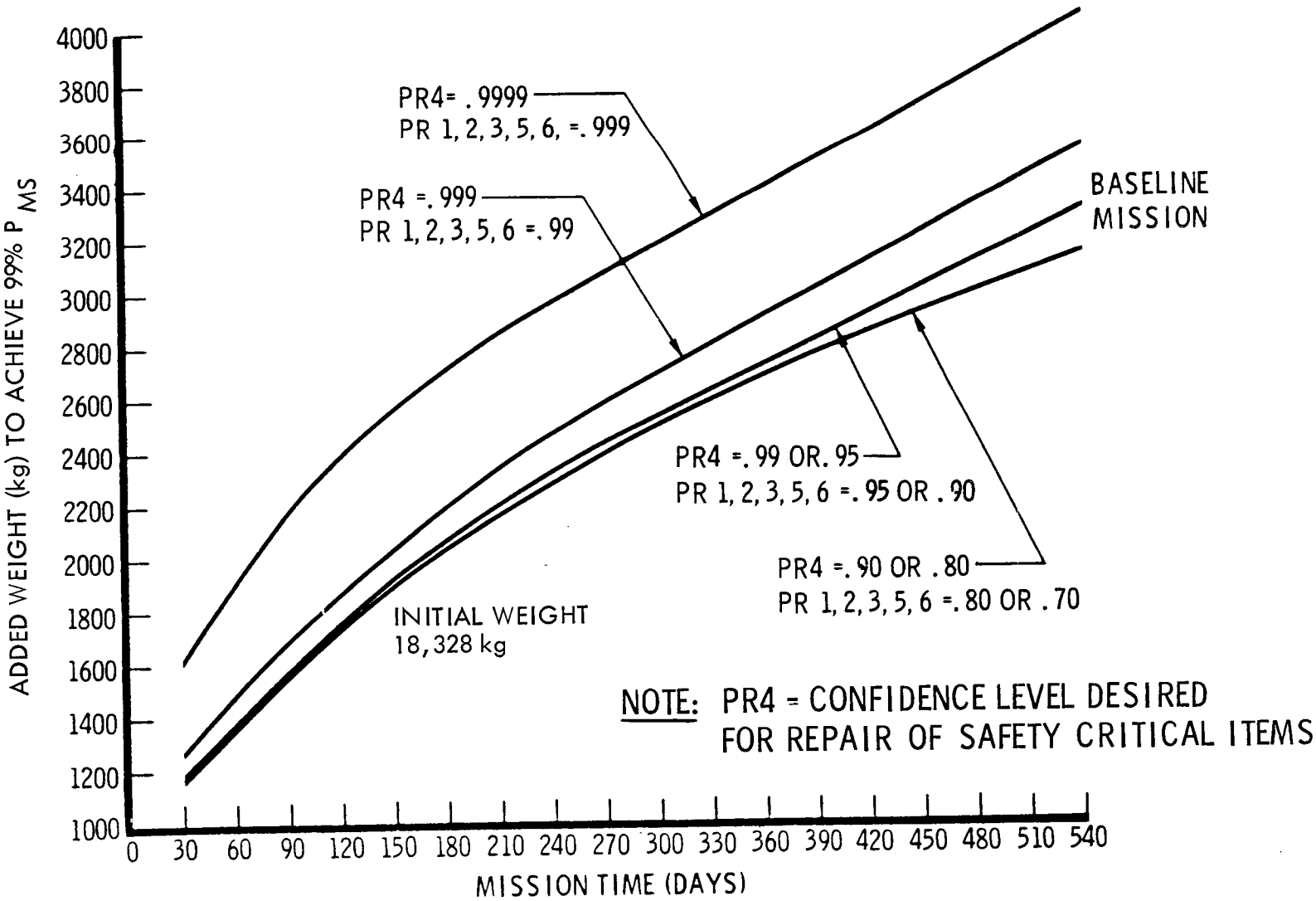


Figure 5.1-2: MISSION TIME VS ADDED WEIGHT FOR CONFIDENCE LEVEL VARIATIONS — 1975 Near-Earth Orbit Mission

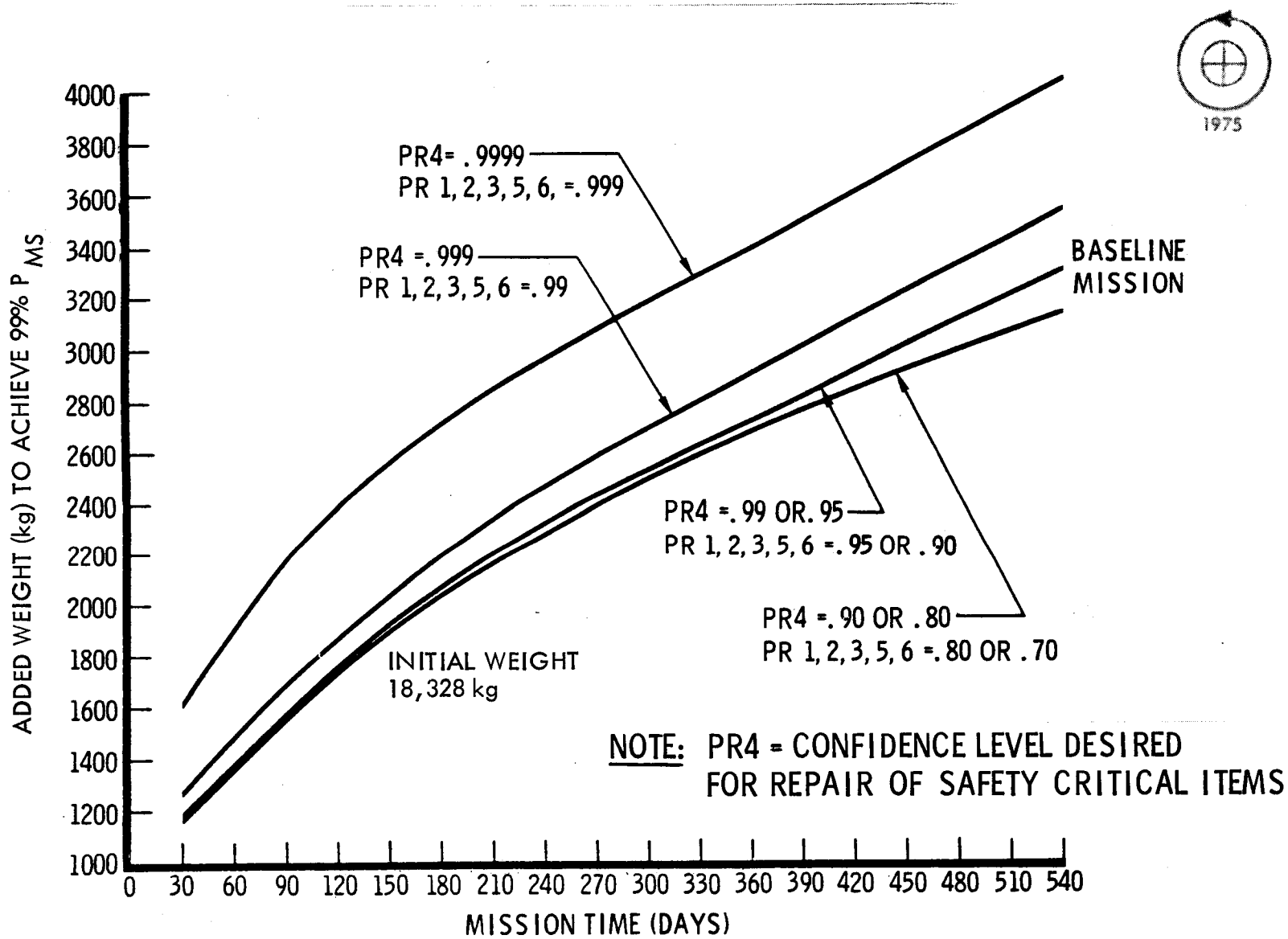


Figure 5.1-2: MISSION TIME VS ADDED WEIGHT FOR CONFIDENCE LEVEL VARIATIONS — 1975 Near-Earth Orbit Mission

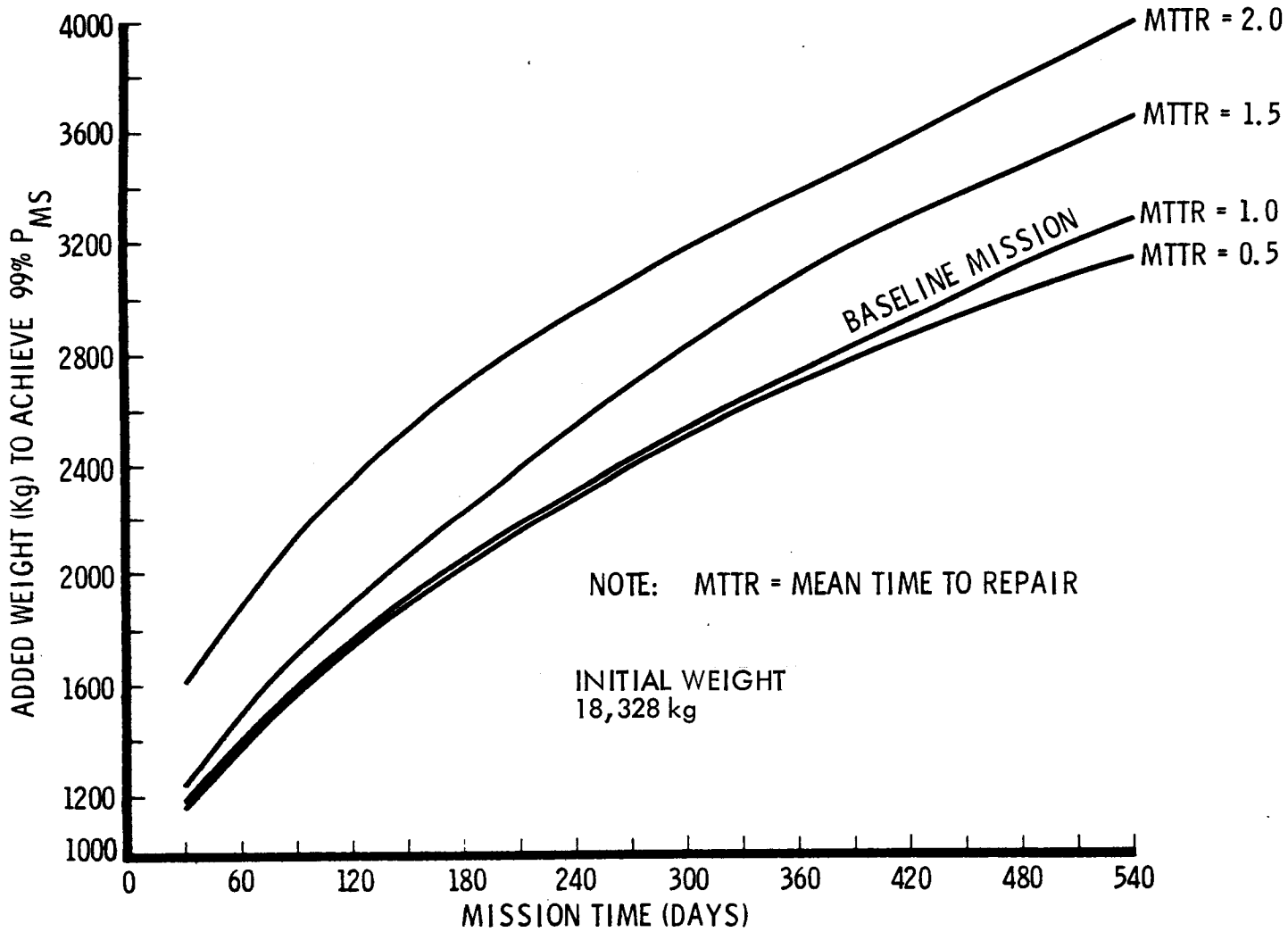


Figure 5.1-3: MISSION TIME VS ADDED WEIGHT FOR MTTR VARIATIONS — 1975 Near-Earth Orbit Mission

To check the sensitivity of results to possible errors in data inputs, the effects of varying component weights, volumes, and failure rates were also investigated. As suspected, a linear relationship was obtained. That is, if the weight and volume of all components is doubled, the total added weight to achieve a desired reliability will be exactly double. It is apparent from the reliability expression, $e^{-\lambda t}$, increasing the failure rate ($\lambda$) by a factor of 2 has the same effect as increasing the mission time (t) by a factor of 2. The results of this study indicated that doubling the failure rate or the mission time time would increase the required spares weight by approximately 25 to 30%, or expressed in another way, halving the failure rate or the mission time would reduce the required spares weight by approximately 20 to 23%.

On all the MARCEP runs, statistics were also gathered on volume added to the system as well as weight. Figure 5.1-4 shows the volume added to the baseline configuration to achieve the desired mission probabilities for different mission times. Figure 5.1-5 illustrates the added volume resulting from varying the desired confidence level of repair. For a 30-day mission time, the added volume varied from about 3.5 to 4.5 cubic meters; for a 180-day mission, the added volume was about 6.5 to 7.2 cubic meters. As a rough estimate, increasing the mission time by six results in about double the added volume.

The previous charts show the weight or volume added for the total spacecraft. Figure 5.1-6 illustrates by subsystem what the initial weight was, and what weight was added, for 90- and 180-day missions to achieve a 99% $P_{MS}$ for the baseline mission. The first item on the left, the data management subsystem, indicates that the weight added exceeded the initial system weight. This was primarily because the system includes a computer and data adapter, which weigh 29 and 74 kilograms, respectively, have relatively high failure rates, and operate practically continuously. The added weight shown was based on replacement of the entire unit whenever a failure occurred. By modularizing the computer and data adapter as indicated, the added weight dropped to 170 kilograms. This is a reduction of 71%. Not only was there a reduction in the added weight for the computer and data adapter, but the optimal selection process resulted in a reduction of the number of spares added to some of the other components in the system. This was because it was more weight-effective to increase the reliability of the computer and data adapter above the previously attained value, which resulted in a reduction in the reliability required for other components to achieve the same total reliability for the data management subsystem as a whole.

The large initial weight and relatively low added weight for the electrical power subsystem was because the solar panels and batteries comprised about three-quarters of the system weight. The solar panels initially were designed for a 5-year life assuming normal degradation, giving a high reliability, and the battery random failure rate was based on a 1-year scheduled replacement of each battery. Consequently, the resulting added weight for 99% $P_{MS}$ was low compared to the initial system weight.

The initial weight shown for experiments included the weight required for a 121-experiment program. Actually, this entire weight would not be on board the spacecraft from the start of the mission, but would be brought up as

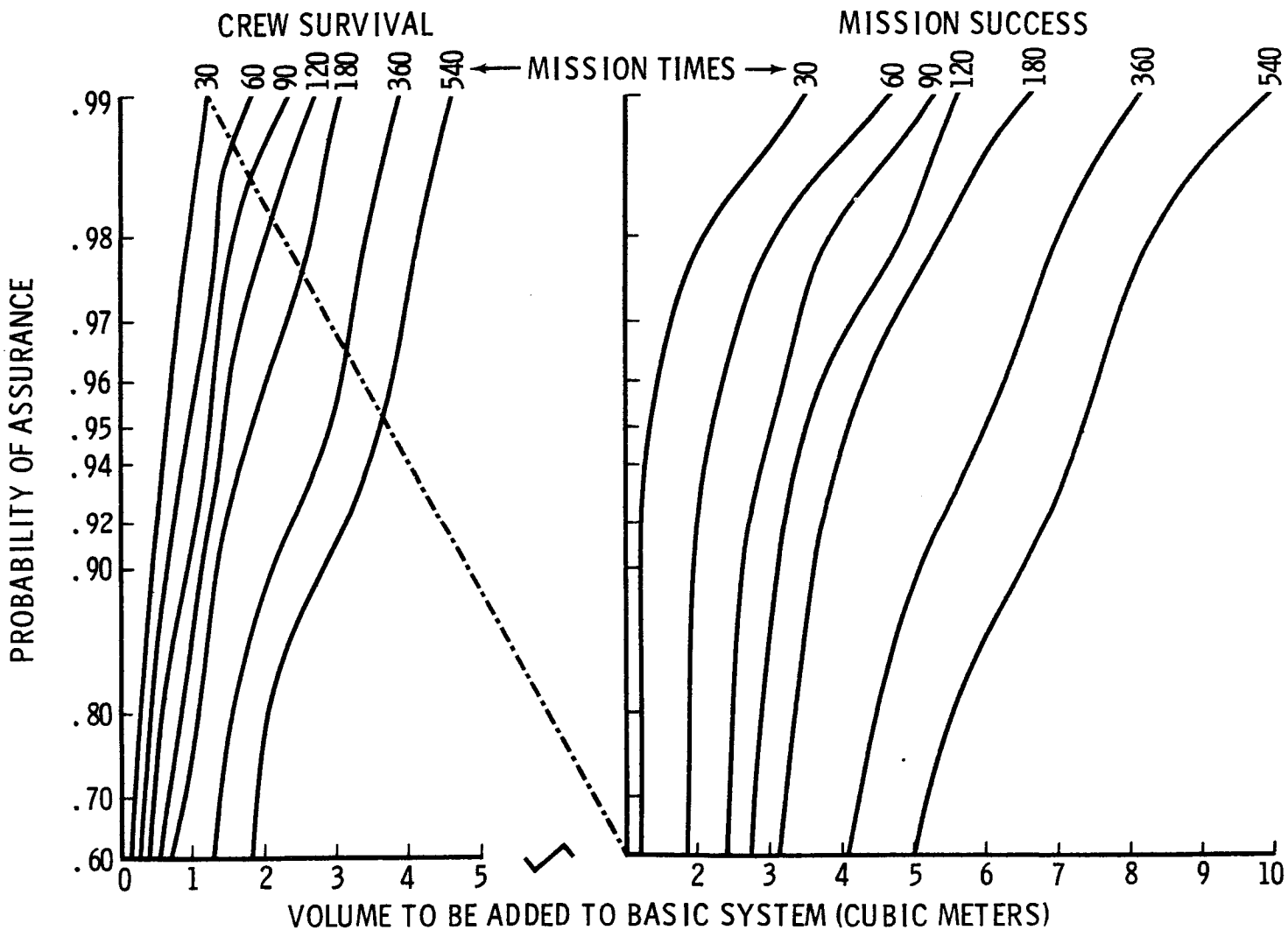


Figure 5.1-4: VOLUME OF COMPONENTS REQUIRED TO ACHIEVE PROBABILITY OF ASSURANCE — 1975 Near-Earth Orbit Mission

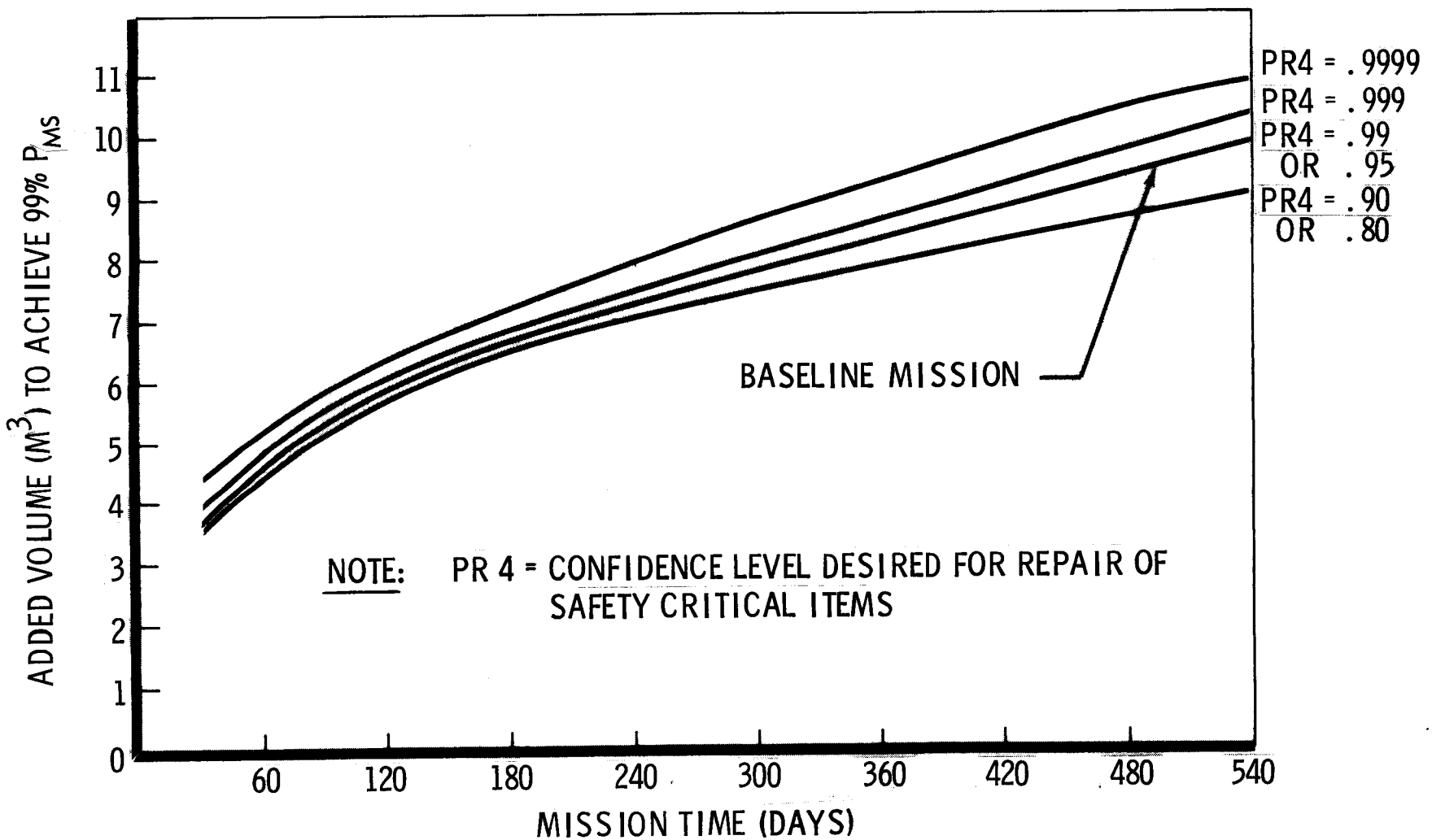


Figure 5.1-5: MISSION TIME VS ADDED VOLUME FOR CONFIDENCE LEVEL VARIATIONS — 1975 Near-Earth Orbit Mission

required during regular resupplies. Most of any redundancy or spares required for any experiment was expected to be provided as part of the experiment. Therefore, the added weight shown was mostly that required to support the experiment airlock, remotely controlled booms, and experiment mounting masts.

The inflight test subsystem again showed the added weight to be about the same as the initial weight. This was due to the large quantity of high-failure-rate display lights and indicators that were included as part of this system.

The low added weight for the reentry system was because the Apollo reentry vehicle would be stowed externally to the mission spacecraft and the equipment would be operated only once every month for checkout purposes. This low operating time resulted in minimum added weight required to achieve mission success.

The big percentage of added weight to initial weight for the stability and control subystem was due to the high-weight control-moment gyros (CMG) used.

The structure has a very low failure rate and therefore a low added weight requirement.

### 5.1.2 1985 $L_1$ LIBRATION CENTER MISSION

Figure 5.1-7 shows the total weight added to the baseline 1985 mission to achieve the desired probabilities of assurance for mission times (resupply intervals) of 120, 180, 270, and 360 days. The increase in added weight, in going from 99% probability of crew survival ($P_{CS}$) to 99% probability of mission success ($P_{MS}$) varied from 35% for the 120-day mission time to 46% for the 360-day mission time. These increases compare with about 50% for the 1975 Earth-orbital mission times. Doubling the mission time from 180 to 360 days resulted in a 27% increase in added weight for 99% $P_{MS}$. This compares with about 30% obtained for the 1975 mission. This again points out the advantage to be gained in terms of more efficient application of the weight added to the basic spacecraft for longer mission durations or resupply intervals. Of the total added weight for 0.99 $P_{MS}$, 183 kilograms are for parallel and standby redundancy for 120- and 180-day mission times. This increased to 199 kilograms of parallel and standby redundancy for 270- and 360-day mission times. The remaining weight is for spares.

Figure 5.1-8 shows the variation in added weight for different confidence levels of repair. This curve reflects a significant increase in added weight only if it is desired to have a 0.9999 confidence of repair for safety critical items. This is basically the same trend as shown for the 1975 mission. As explained in Section 5.1.1, a confidence level of greater than 0.99 is not thought to be compatible with the other mission criteria.

Figure 5.1-9 shows the variation in added weight for different MTTR changes from the baseline system. As indicated for 1975 also, the only

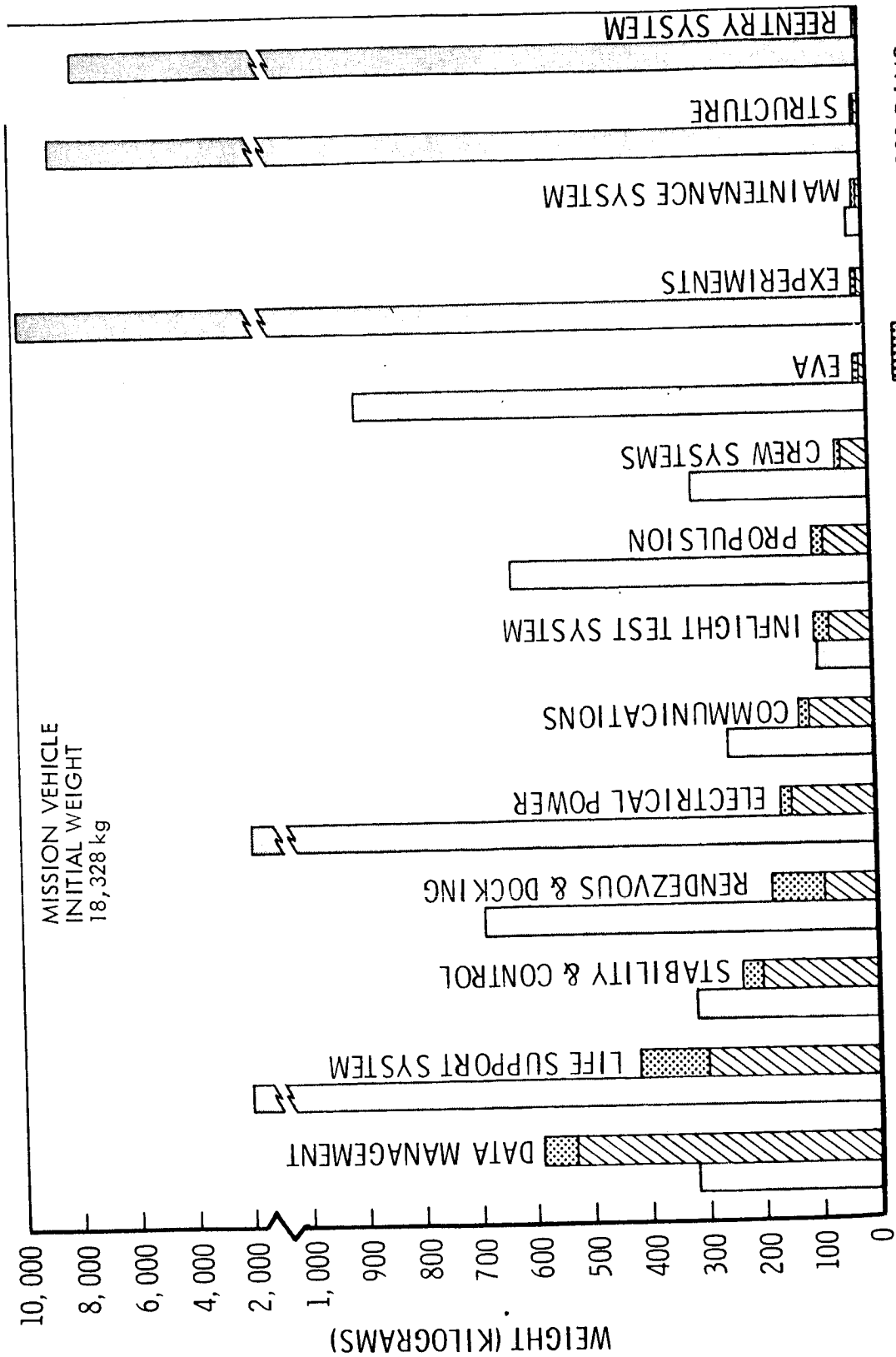


Figure 5.1-6: SUBSYSTEM INCREMENTAL WEIGHTS — 1975 Near-Earth Orbit Mission

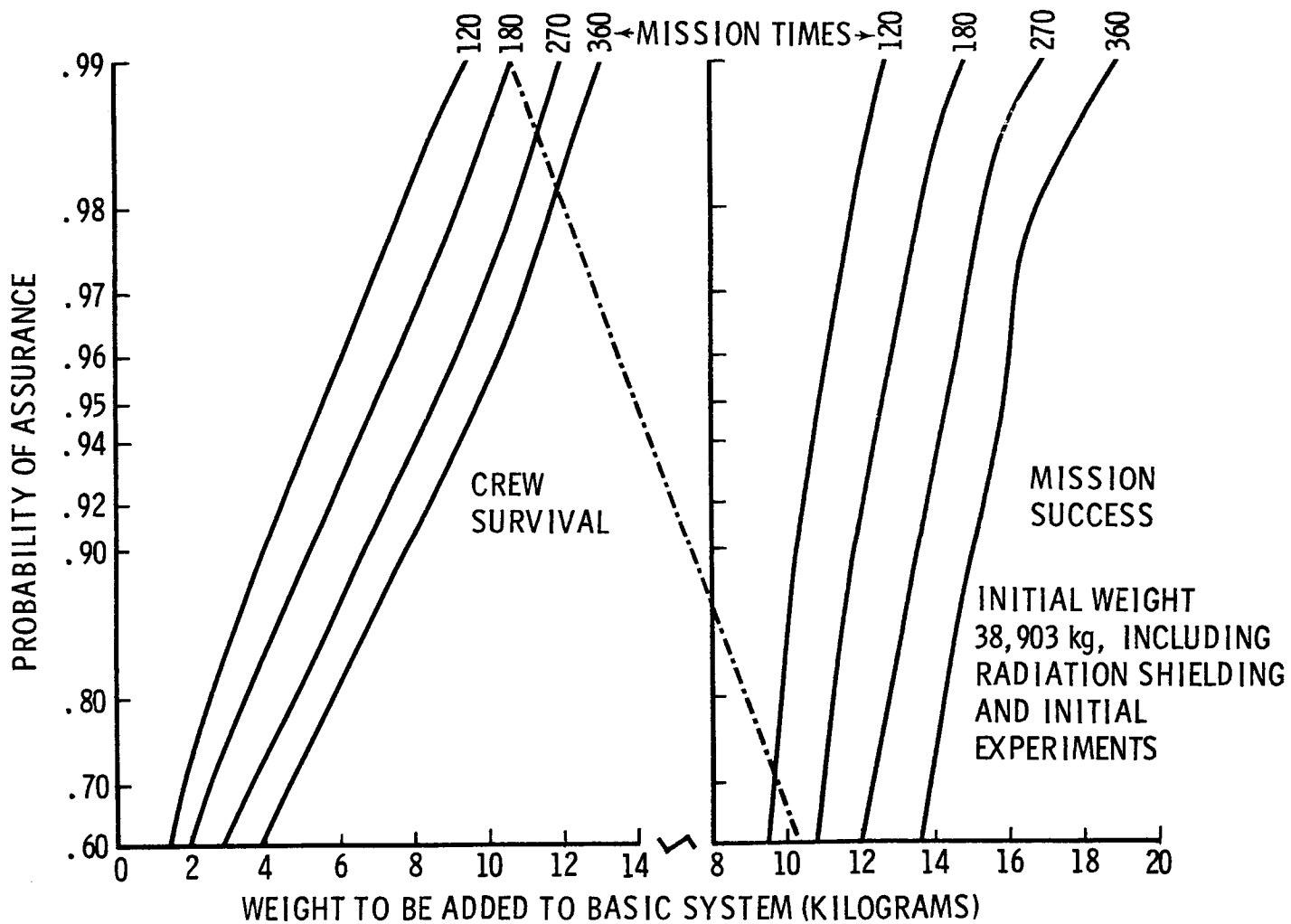


Figure 5.1-7: ADDITIONAL WEIGHT REQUIRED TO ACHIEVE PROBABILITY OF ASSURANCE — 1985 $L_1$ Libration Center Mission

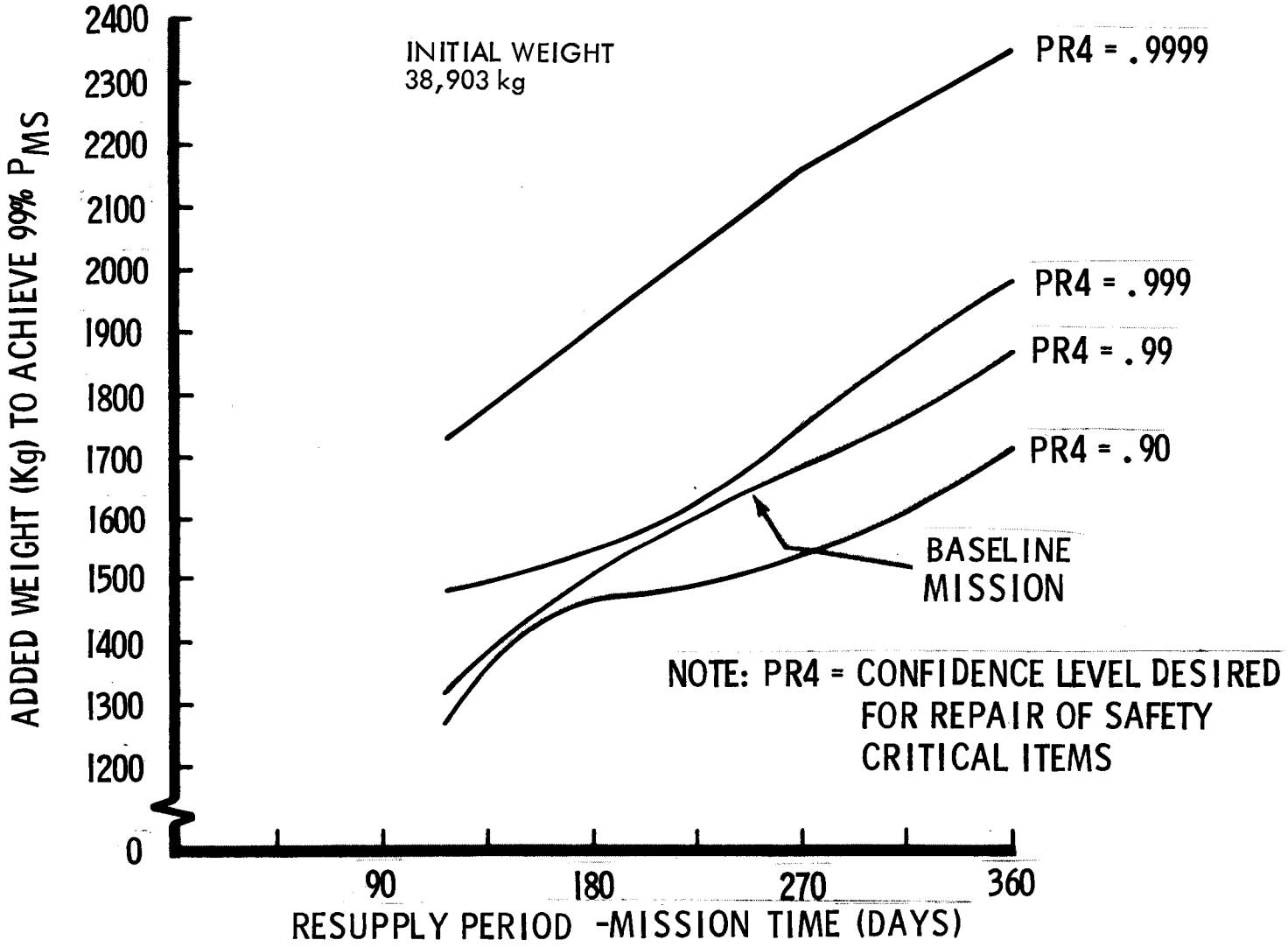


Figure 5.1-8: MISSION TIME VS ADDED WEIGHT FOR CONFIDENCE LEVEL VARIATIONS — 1985 $L_1$ Libration Center Mission

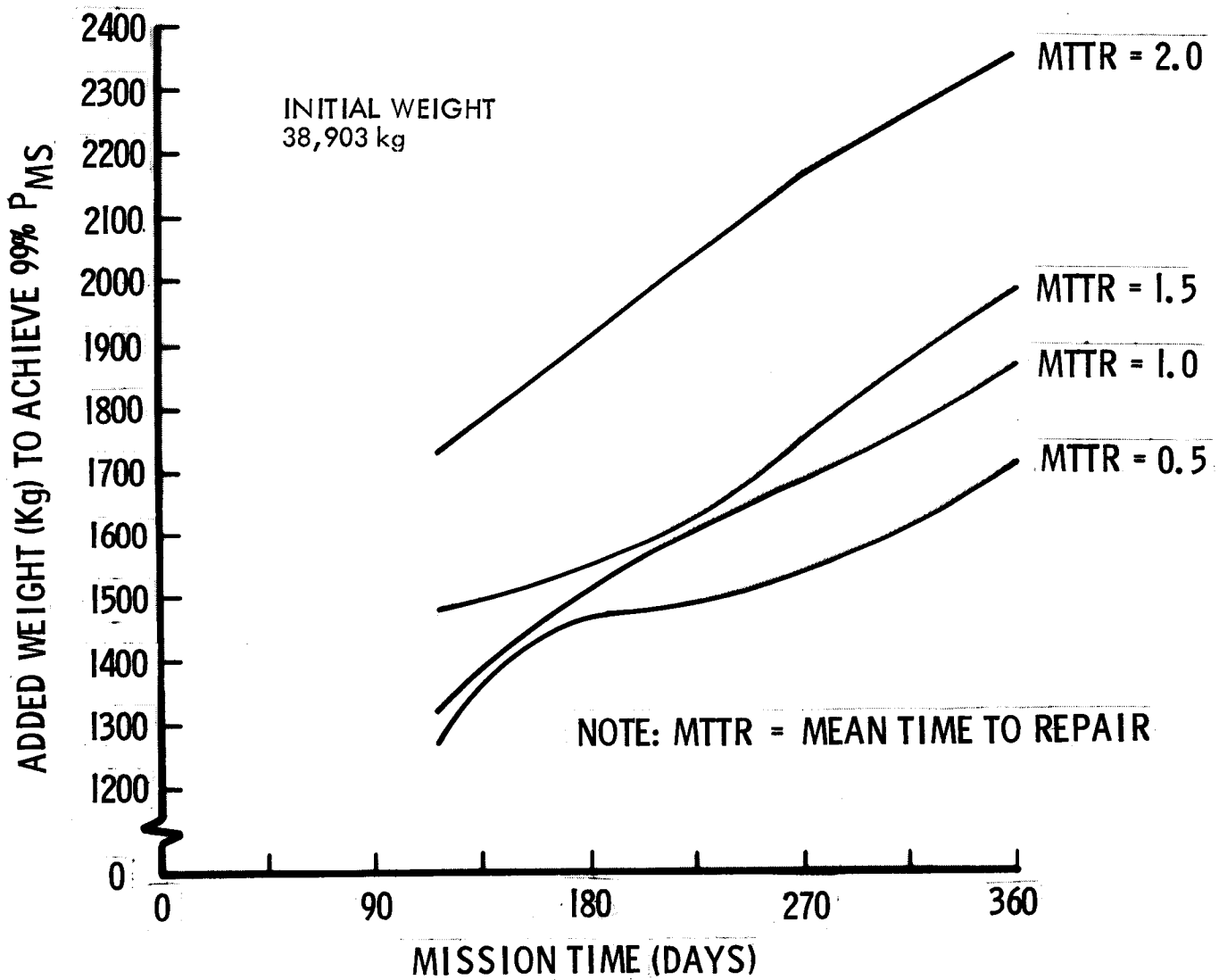


Figure 5.1-9: MISSION TIME VS ADDED WEIGHT FOR MTTR VARIATIONS — 1985 $L_1$ Libration Center Mission

significant increase is shown for MTTR factors of 2.0 times the baseline system values for each component. In comparing Figures 5.1-8 and 5.1-9 the added weight curves for PR-4 values of 0.90, 0.99, 0.999, and 0.9999 are almost exactly the same as for MTTR factors of 0.5, 1.0, 1.5, and 2.0, respectively.

Data was also obtained on the volume added to the system as well as weight. Figure 5.1-10 shows the volume added to the baseline configuration to achieve the required mission probabilities for different mission times. Figures 5.1-11 and 5.1-12 show the added volume for variations of MTTR factors and repair confidence levels.

Figure 5.1-13 illustrates for each subsystem the initial weight of the subsystem and the weight added for 180- and 360-day resupply intervals. The comments made in Section 5.1.1 on the similar chart for the 1975 mission in general are applicable for this chart as well; the initial and added weights for the data management system are considerably less. The initial weight of the system is lower because of the increased capability from lighter weight components assumed for 1985. In addition, as a result of the trade made for the 1975 mission, it was assumed that the computer and data adapter were modularized.

A more extensive analysis of the effect of equipment modularization was made for the 1985 mission. In this analysis it was assumed that many of the heavier electrical or electronic components consisted of replaceable modules or subassemblies. For the 180-day resupply interval, this resulted in reducing the added weight to the total spacecraft by 94 kilograms, which is about 6.3% of the 1489 kilograms added initially. The weight reductions by subsystem are discussed below.

1) Life Support System--The added weight to this system was reduced by 8 kilograms. Although there was no modularization of components assumed here, the reduction was due to the side effects of modularizing the components of the data management system, as discussed in Section 5.1.1.

2) Communications--A reduction of 20 kilograms resulted from assuming that the unified S-band transceiver equipment, which weighs 22 kilograms, could be broken down into 30 modules of 12 different types.

3) Data Management--A reduction of 8 kilograms was obtained from modularizing the 12-kilogram electronic scanner into 15 modules of 5 different types.

4) Rendezvous and Docking--A reduction of 12 kilograms resulted from assuming that the 6.8-kilogram radar transponder would consist of 13 modules of 6 different types.

5) Navigation and Guidance--A reduction of 21 kilograms was obtained by assuming that the 15-kilogram inertial platform consisted of 19 modules of 8 different types.

6) Inflight Test System--A reduction of 16 kilograms was realized by assuming that the manual test unit, test display, and control unit each consisted of 8 modules of 4 different types; and the safety monitor unit consisted of 30 modules of 6 different types.

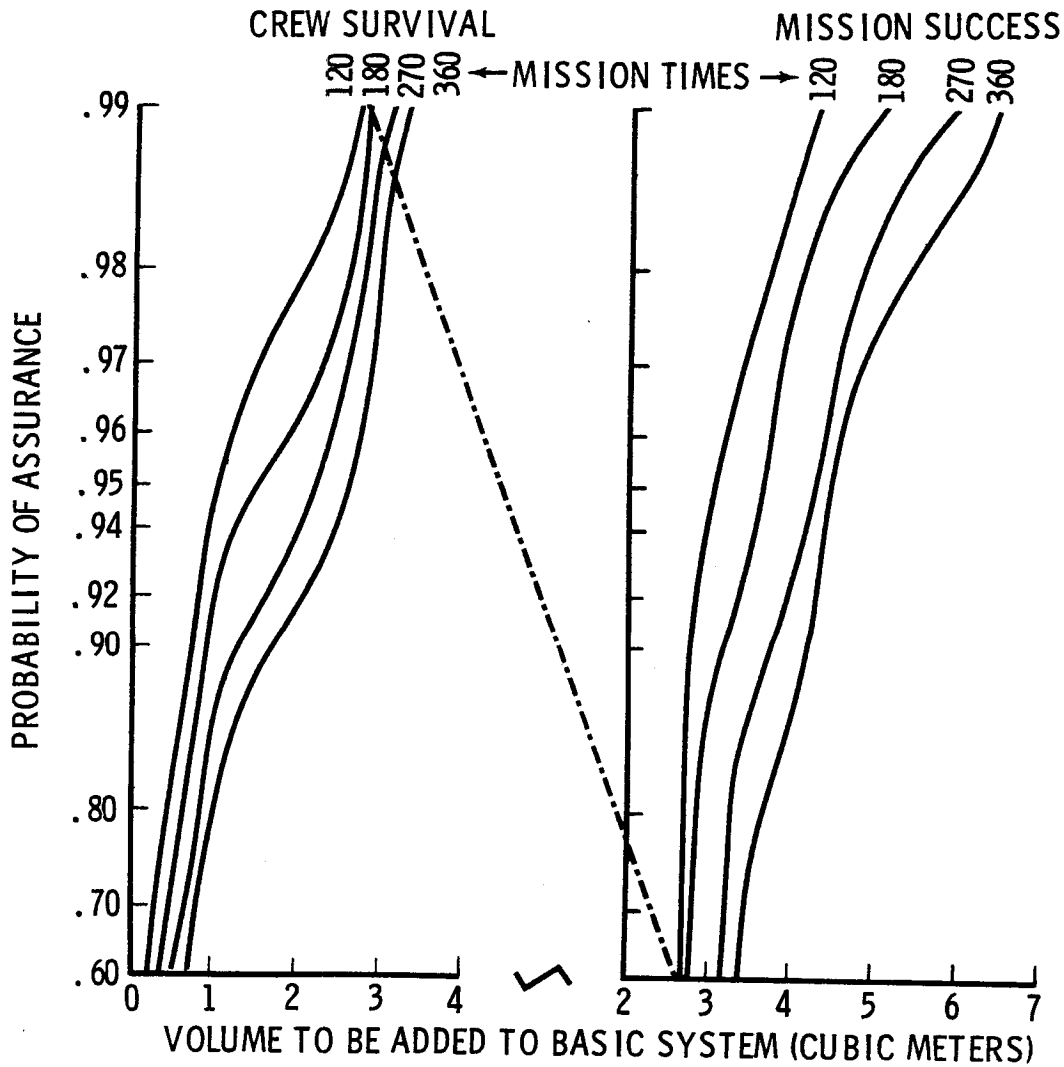


Figure 5.1-10: VOLUME OF COMPONENTS REQUIRED TO ACHIEVE PROBABILITY OF ASSURANCE — 1985 $L_1$ Libration Center Mission

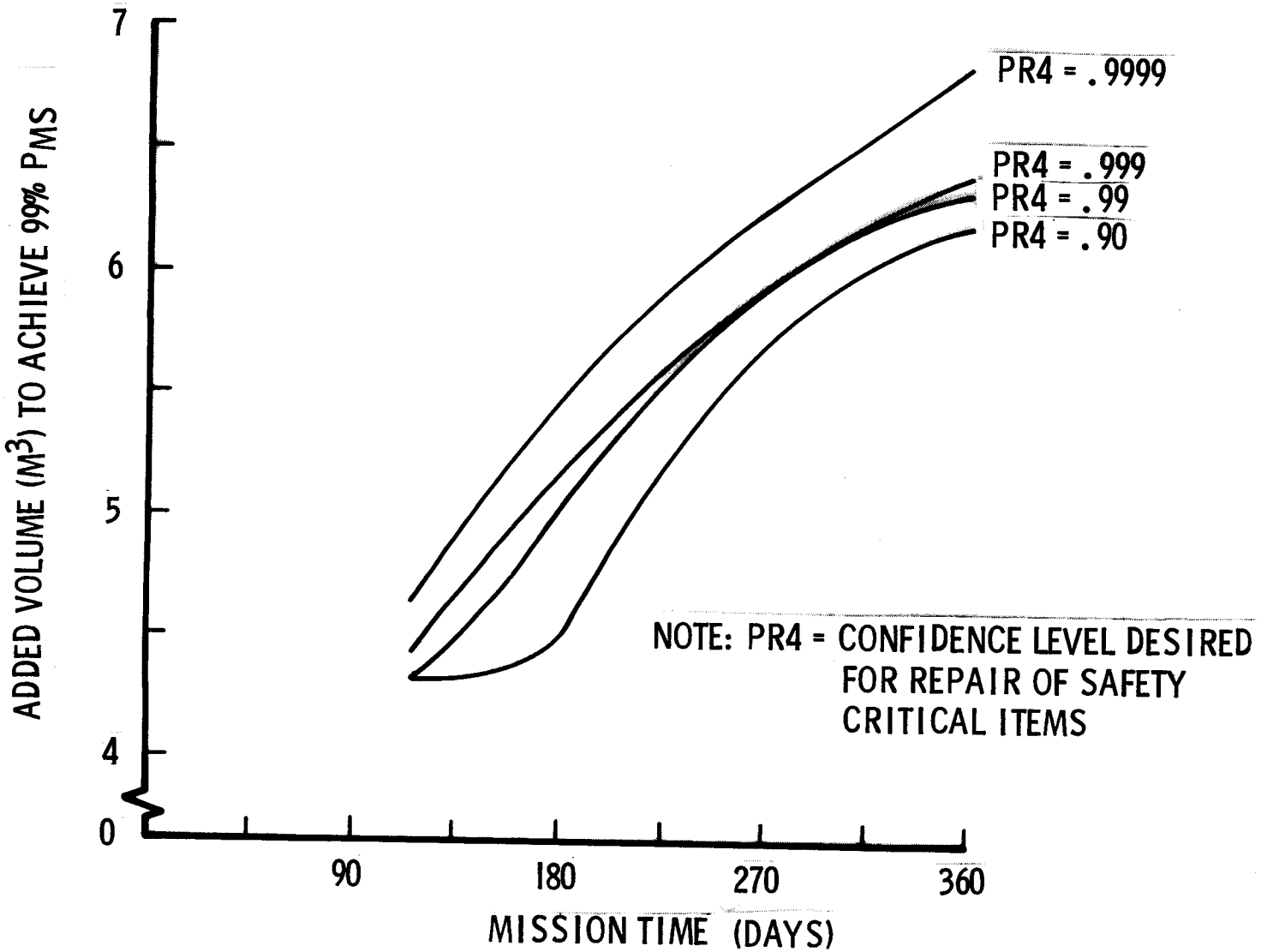


Figure 5.1-11: MISSION TIME VS ADDED VOLUME FOR CONFIDENCE LEVEL VARIATIONS — 1985 $L_1$ Libration Center Mission

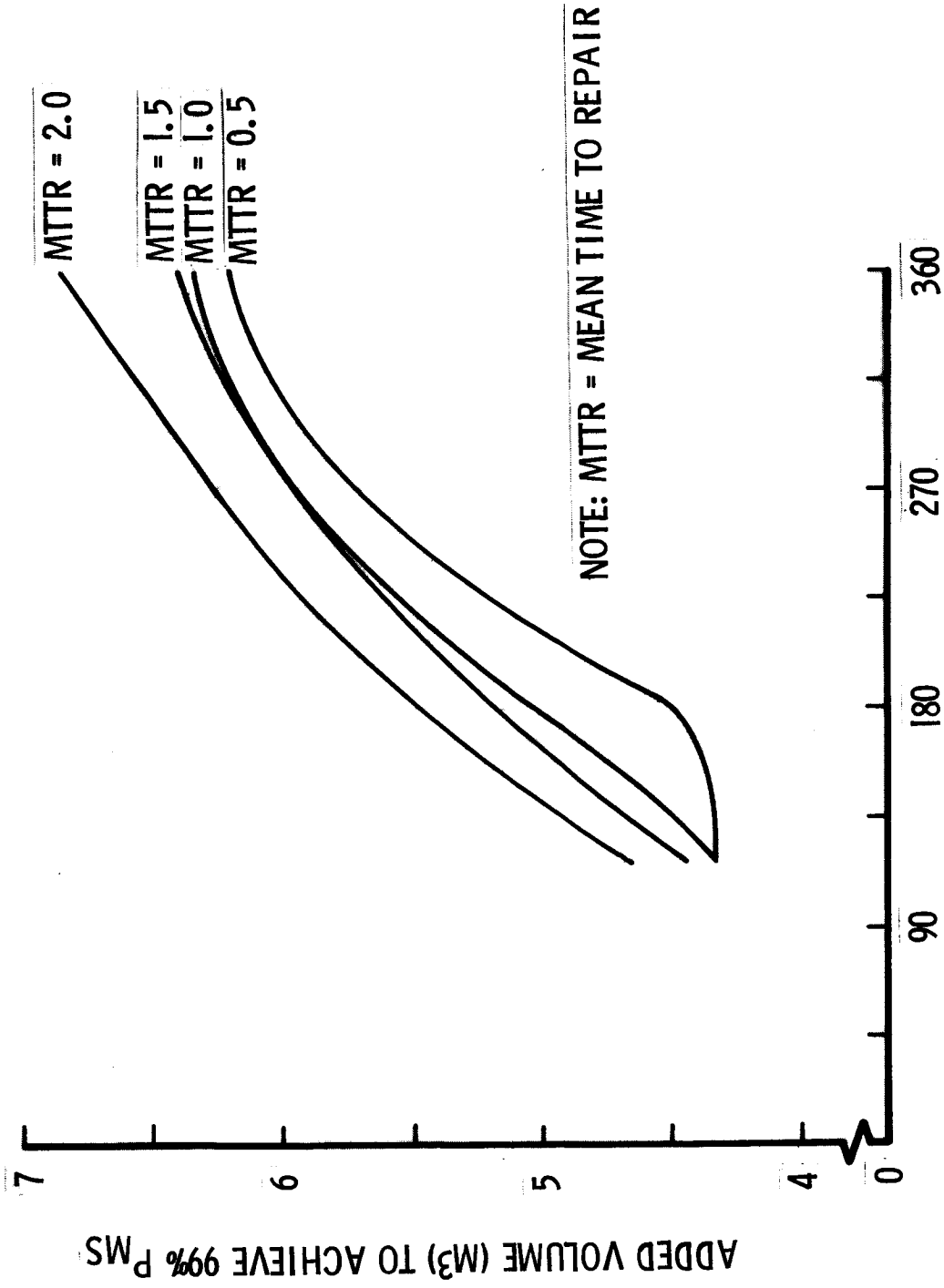


Figure 5.1-12: MISSION TIME VS ADDED VOLUME FOR MTTR VARIATIONS — 1985 $L_1$ Libration Center Mission

Figure 5.1-13: SUBSYSTEM INCREMENTAL WEIGHTS — 1985 $L_1$ Libration Center Mission

7) Crew System--A reduction of 9 kilograms resulted, although no changes were assumed.

No weight reduction was shown for the other systems.

## 5.2 EFFECTS OF SCHEDULED MAINTENANCE ON OVERALL MISSION REQUIREMENTS

The scheduled maintenance requirements, which by definition occur at preplanned time intervals instead of randomly, could be calculated manually and it was not necessary for this study to include these requirements in the mission simulation program. The maintenance task analysis, performed on each of the approximately 550 component types identified during the study for each mission, specified the scheduled maintenance required to keep the spacecraft system in a satisfactory operationg condition. The task analysis forms are included in Volume III. The following paragraphs summarize these scheduled maintenance requirements for each of the Earth-orbital missions.

### 5.2.1 1975 NEAR-EARTH ORBITAL MISSION

Table 5.2-1 summarizes the scheduled maintenance requirements for this mission within each frequency interval, by minutes required for each skill level to perform the task. If more than one task of one type is indicated, as shown in parentheses, the time is the total required. The code number refers to the resource identification as listed in Table 5.2-2 and also as used in the maintenance task analysis sheets in Volume III. Lamps for various types of lighting equipment are shown as scheduled replacement items, whereas they actually will not be replaced until they burn out. The replacement schedule is based on the average expected lamp wearout life. Resources required to perform the scheduled maintenance are indicated on the table by the resource set code numbers that are given in Volume III.

The tasks that require EVA are noted, as indicated at the bottom of Sheet 3 of Table 5.2-1. The number of extravehicular trips required per year will vary from 37 to 54, depending on how many of the tasks can be combined into each EV excursion.

The scheduled maintenance shown in Table 5.2-1 accomplished under the resupply heading can only be done at that time and not apportioned over a number of days. The total estimated time required was 1340 man-minutes (22.3 manhours). However, the additional crewmen that arrive with the resupply vehicle will assist in performing the resupply tasks, so the total manhours would not be charged to the basic eight-man spacecraft crew. The detailed expendable requirements that must be resupplied periodically are shown on data sheets in Volume III. A summary of these resupply requirements by system is presented in Figure 5.2-3.

The scheduled maintenance shown for a 360-day interval includes only scheduled replacements based on an expected wearout life for the components. These scheduled replacements probably would be planned to spread the workload over several weeks once the mission has completed the first 360 days; 7930 man-minutes are required to complete the yearly scheduled maintenance. For

Table 5.2-1: SCHEDULED MAINTENANCE---1975 NEAR-EARTH ORBITAL MISSION

| Code | Item | Task | Time/Skill (min) LS | EE | ME | ST | CM | Resources |
|---|---|---|---|---|---|---|---|---|
| | | DAILY | | | | | | |
| IF | Console Displays | Check and record readings | | 10 | | | | |
| LS | Life Support System | General gross checks | 10 | | | | | |
| | | 3 DAYS | | | | | | |
| LS 15 | Carbon Collection Bag | Replace bag (2 at 15 min each) | 30 | | | | | 1,2 |
| | | 7 DAYS | | | | | | |
| CS | Sponge, Disinfectant, Vacuum Cleaner | General interior cleaning | 180 | | 180 | | | |
| LS 108 | Urine Filter | Replace filter (2) | 30 | | | | | |
| LS | Life Support System | General inspection | 30 | | | | | |
| | | 21 DAYS | | | | | | |
| LS 38 | Evaporation Wick | Replace wick (4) | 60 | | | | | |
| | | 30 DAYS | | | | | | |
| LS 44 | Charcoal Filter, Gas | Replace filter (4) | 60 | | | | | 1,2 |
| LS 45 | Charcoal Filter, Fluid | Replace filter (4) | 80 | | | | | 1,33 |
| LS 77 | Charcoal and Particulate Filter | Replace filter (4) | 60 | | | | | 1,2 |
| LS 78 | Absolute Filter | Replace filter (2) | 30 | | | | | 1,2 |
| LS 87 | Catalytic Cartridge | Replace cartridge (4) | 80 | | | | | 1,2 |
| LS 164 | Gas Chromatograph | Calibrate | | 60 | | | | |
| LS 165 | Mass Spectrometer | Calibrate | | 60 | | | | |
| LS | Life Support System | Check instrumentation, operate manual valves | 60 | | | | | |
| CS 25 | Vacuum Cleaner | Replace bag | | | 10 | | | |
| CS 26 | Fire Extinguishers | Inspect | | | 30 | | | |

Table 5.2-1: SCHEDULED MAINTENANCE---1975 NEAR-EARTH ORBITAL MISSION (Cont)

| Code | Item | Task | Time/Skill (min) LS | EE | ME | ST | CM | Resources |
|---|---|---|---|---|---|---|---|---|
| | | 30 DAYS (Cont) | | | | | | |
| RE | Reentry System | Checkout† | | 60 | | | 60 | 1,15,16 |
| ST | Structure | Inspect spacecraft exterior† | | | 120 | 120 | | 1,6,15,16 |
| IF 4,5 | Indicators, Display | Replace lamp (3) | | 30 | | | | |
| | | 90 DAYS | | | | | | |
| LS 43 | Conductivity Sensor | Calibrate (4) | | 120 | | | | 1,9 |
| LS 113 | Odor Filter | Replace filter (2) | 60 | | | | | 1 |
| LS 162 | $O_2$ Partial Pressure Sensor | Replace element (4) | 40 | | | | | 1 |
| LS 163 | $CO_2$ Partial Pressure Sensor | Replace element (4) | 40 | | | | | 1 |
| CS 17 | Film Viewer | Inspect and clean | | 15 | | | | 1,2 |
| CS 20 | Microfilm Reader | Inspect and clean | | 15 | | | | 1,2 |
| DM 6 | Typewriter | Inspect and clean | | 60 | | | | 1,2 |
| DM 8 | Console Viewer | Inspect and clean | | 15 | | | | 1,2 |
| DM 11 | Film Projector/Scanner | Inspect and clean | | 15 | | | | 1,2 |
| RE | Reentry System | Extensive checkout*† | | 120 | | | 120 | 1,15,16 |
| RD | Docking System | Inspect and lubricate† | | | 90 | 90 | | 1,12,15,16 |
| EX | Experiment Airlock | Lubricate mechanisms | | | 30 | | | 1,12 |
| CS 33 | Lamp, Incandescent | Replace lamp | | 10 | | | | |
| CS 34 | Lamp, Fluorescent | Replace lamp (2) | | 20 | | | | |
| DM 9 | Projection Lamp | Replace lamp | | 20 | | | | |

*The 30- and 90-day checkout will be integrated resulting in a total checkout time of 180 minutes.

†Extravehicular activity (EVA) is required for all or part of these scheduled maintenance tasks.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | RESUPPLY | | | | | | |
| LS 25 | Electrolysis Module | Replenish electrolyte (3) | 90 | | | | | 1 |
| LS 55 | Oxygen Tanks | Replenish oxygen (2) | 60 | | 60 | | | 1 |
| LS 56 | Nitrogen Tanks | Replenish nitrogen (2) | 60 | | 60 | | | 1 |
| LS 62 | Water Tanks | Replenish water | 30 | | 30 | | | 1 |

Table 5.2-1: SCHEDULED MAINTENANCE---1975 NEAR-EARTH ORBITAL MISSION (Cont)

| Code | Item | Task | Time/Skill (min) LS | EE | ME | ST | CM | Resources |
|---|---|---|---|---|---|---|---|---|
| LS 66 | Wash Water Chemical | Replenish chemical | 20 | | | | | |
| LS 106 | Food Container | Replenish food | 180 | | 180 | | | |
| LS 112 | Feces Bags | Replenish bags | 30 | | | | | |
| PP | Propellants | Replenish propellants | | | 120 | 120 | | 1,33 |
| PP | Nitrogen Pressurant | Replenish nitrogen | | | 120 | 120 | | 1,33 |
| CS | Clothing and Personal Items | Replenish supplies | | | 60 | | | |
| EV 2 | LiOH Canisters | Replenish canisters | 30 | | | | | |
| | | 360 DAYS | | | | | | |
| EP 2 | Battery | Replace battery (6) | | 720 | 720 | | | 1,10 |
| PP 27 | Engine, 50 lb Thrust | Replace engine (18)† | | | 2160 | 2160 | | 1,15,16 |
| PP 28 | Engine, 150 lb Thrust | Replace engine (8)† | | | 960 | 960 | | 1,15,16 |
| DM 12 | Projection Lamp | Replace lamp | | 25 | | | | |
| EP 5 | Voltage Regulator | Replace regulator | | 120 | | | | 1 |
| EP 7 | Battery Charge Regulator | Replace regulator | | 90 | | | | 1 |
| | | 600 DAYS | | | | | | |
| LS 13 | Bosch Reactor | Replace catalyst (2) | 240 | | 240 | | | 1,2 |
| | | 800 DAYS | | | | | | |
| EP 4 | Inverter | Replace inverter | | 80 | | | | 1 |

†Extravehicular activity (EVA) is required for all or part of these scheduled maintenance tasks.

Table 5.2-2: MAINTENANCE EQUIPMENT

| Task Analysis Reference No. | Equipment Nomenclature | Subsystem Reference No. |
|---|---|---|
| 1 | Standard Tool Kit (wrenches, pliers, screwdrivers, personnel and tool restraints, multimeter, flashlight, tape, fluid-containing bags, etc.) | ME 1 |
| 2 | Vacuum System | ME 2 |
| 3 | Space Power Tool Kit | ME 3 |
| 4 | Electron-Beam Welder | ME 4 |
| 5 | Stemfab Tool | ME 5 |
| 6 | Leak Detection Equipment | ME 6 |
| 7 | Temperature Measuring Device | ME 7 |
| 8 | Pressure Measuring Device | ME 8 |
| 9 | Water Test Kit | ME 9 |
| 10 | Battery Test Kit | ME 10 |
| 11 | Electrical Repair Kit | ME 11 |
| 12 | Lubrication Kit | ME 12 |
| 13 | Fabric Repair Kit | ME 13 |
| 14 | Airflow Meter | ME 14 |
| 15 | EVA Restraint Aids | EV 10 |
| 16 | EVA Tether Cable | EV 11 |
| **Special Maintenance Kits** | | |
| 30 | External Structure | ST 17 |
| 31 | Internal Structure | ST 16 |
| 32 | Space Radiator | LS 167 |
| 33 | Plumbing and Ducts | LS 166 |
| 34 | Battery Case | EP 18 |
| 35 | Experiments | EX 37 |
| 36 | Reentry System | RE 18 |
| 37 | Spacesuit and Backpack | EV 13 |
| 38 | Airlock | EV 14 |
| 39 | Modular Maneuverable Unit (MMU) | EV 15 |
| 40 | Remote Maneuverable Unit and Astronaut Encapsulation/Vehicle (RMU and AE/V) | EV 16 |
| 41 | Restraint Aids | EV 12 |
| 42 | Pumpdown System Storage Tank | LS 174 |

Note: Technical data is provided as part of the data management subsystem and test equipment such as meters, scopes, etc., are part of the in-flight test subsystem. See Volume III for discussions of these subsystems.

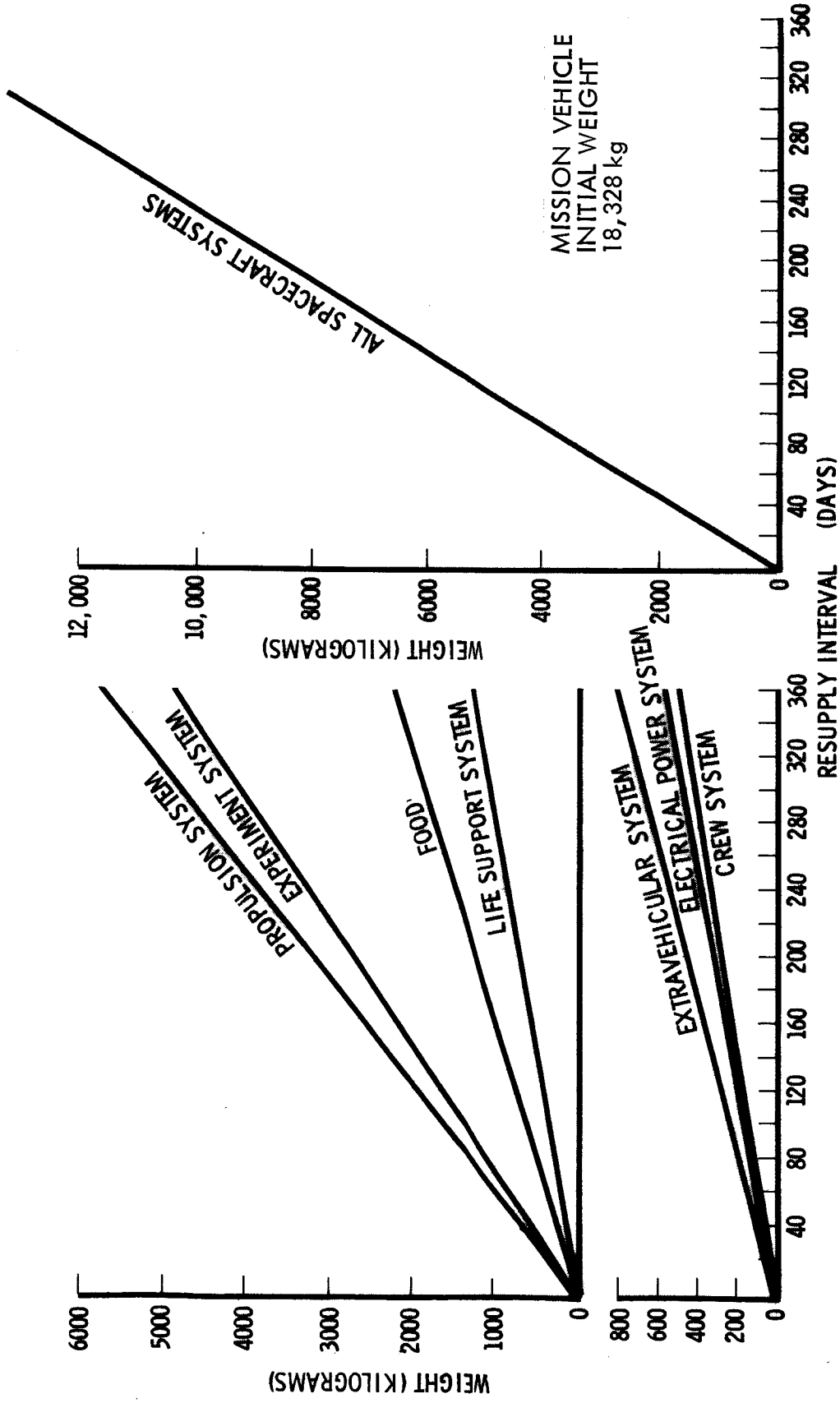


Figure 5.2-3: RESUPPLY AND EXPENDABLE REQUIREMENTS — 1975 Near-Earth Orbit Mission

comparison, this averages out to about 22 man-minutes per day, which adds about 16% to the 133.2 man-minutes per day calculated for the basic scheduled maintenance workload. About 79% of the 360-day maintenance workload is contributed by the 1-year service life of the reaction control engines. Battery replacements account for another 18% of the workload. If the service life of these engines and batteries could be extended, this annual workload would be considerably reduced. The replacements required at 600 and 800 days contribute so little to the overall maintenance workload that they can be neglected as an influence on the analysis.

Table 5.2-4 summarizes the total man-minutes and average man-minutes per day for the scheduled maintenance required at 1-, 3-, 7-, 21-, 30- and 90-day intervals for each subsystem. It is expected that these tasks could be apportioned over all the days in each 90-day interval so the workload would be evenly distributed over each day. An average of 133.2 man-minutes (2.2 man-hours) per day are required through the 90-day period to complete the scheduled maintenance indicated. The life support system and the crew system, which includes the general housekeeping functions, together account for about 78% of the scheduled maintenance.

Table 5.2-5 shows a breakdown of the total and average man-minutes per day for each crew skill specialty. More than 50% of the scheduled maintenance requires the life support system skill. This is primarily due to the numerous replacements of filter, cartridges, and wicks.

### 5.2.2 1985 $L_1$ LIBRATION CENTER MISSION

The maintenance task analysis sheets used for this mission to identify the scheduled maintenance requirements are included in Volume III. The scheduled maintenance functions required are basically the same as for the 1975 near-Earth orbital mission, except that some of the intervals between tasks were increased and some of the times to perform the tasks were decreased to reflect expected improvements by 1985.

Table 5.2-6 summarizes the scheduled maintenance requirements by the frequency interval and minutes required by each skill level to perform the task. The scheduled maintenance shown here for intervals greater than 90 days includes only scheduled replacements based on expected wearout life. The average man-minutes per day for these tasks is about 6.0; 75% is caused by the 720-day scheduled replacement of the battery and reaction control engines. However, a large improvement has been shown from the 1975 mission because of a reduction in the number and replacement frequency of batteries and engines. The resource identification is given in Table 5.2-2.

The tasks requiring EVA are identified in the table. The number of EV trips required per year will vary from 16 to 28, depending on how many of the tasks can be combined into each EV trip.

The maintenance required at the resupply intervals is also shown in Table 5.2-6. A summary of the expendables requirements that must be resupplied periodically is given in Figure 5.2-7. The detailed expendable requirements are included in Volume III.

Table 5.2-4: SUBSYSTEM SCHEDULED MAINTENANCE REQUIREMENTS--- 1975 NEAR-EARTH ORBITAL MISSION

| Subsystem | Man-Minutes/Maintenance Interval (days) 1 | 3 | 7 | 21 | 30 | 90 | Average Man-Minutes/Day |
|---|---|---|---|---|---|---|---|
| Life Support | 10 | 30 | 60 | 60 | 490 | 260 | 51.0 |
| Crew System | | | 360 | | 40 | 40 | 52.6 |
| Inflight Test | 10 | | | | 30 | | 11.4 |
| Reentry System | | | | | 120 | 240 | 6.7 |
| Structure | | | | | 240 | | 8.0 |
| Rendezvous and Docking | | | | | | 180 | 2.0 |
| Data Management | | | | | | 110 | 1.2 |
| Experiment System | | | | | | 30 | 0.3 |
| Total Man-Minutes | 20 | 30 | 420 | 60 | 920 | 860 | |
| Average Man-Minutes/Day | 20 | 10 | 60 | 2.9 | 30.7 | 9.6 | 133.2 |

NOTE: Scheduled maintenance required at intervals greater than 90 days and at the resupply periods are not shown in the above summary as these tasks must be done at about the time indicated and cannot realistically be apportioned over a number of days.

Table 5.2-5: SCHEDULED MAINTENANCE CREW SKILL REQUIREMENTS---
1975 NEAR-EARTH ORBITAL MISSION

| Crew Skill | Man-Minutes/Maintenance Interval (days) 1 | 3 | 7 | 21 | 30 | 90 | Average Man-Minutes/Day |
|---|---|---|---|---|---|---|---|
| Life Support Systems | 10 | 30 | 240 | 60 | 370 | 140 | 71.09 |
| Electrical/Electronic | 10 | | | | 210 | 390 | 21.33 |
| Mechanical | | | 180 | | 160 | 120 | 32.36 |
| Structures | | | | | 120 | 90 | 5.00 |
| Communications | | | | | 60 | 120 | 3.33 |
| Total Man-Minutes | 20 | 30 | 420 | 60 | 920 | 860 | |
| Average Man-Minutes/Day | 20 | 10 | 60 | 2.9 | 30.7 | 9.6 | 133.2 |

NOTE: Scheduled maintenance required at intervals greater than 90 days and at the resupply periods are not shown in the above summary as such tasks must be done at about the time indicated and cannot realistically be apportioned over a number of days.

Table 5.2-6: SCHEDULED MAINTENANCE---1985 $L_1$ LIBRATION CENTER MISSION

| Code | Item | Task | Time/Skill (min) LS | EE | ME | ST | CM | Resources |
|---|---|---|---|---|---|---|---|---|
| | | DAILY | | | | | | |
| IF | Console Displays | Check and record readings | | 10 | | | | |
| LS | Life Support System | General gross checks | 10 | | | | | |
| | | 7 DAYS | | | | | | |
| LS 15 | Carbon Collection Bag | Replace bag (2 at 15 min each) | 30 | | | | | 1,2 |
| CS | Sponge, Disinfectant, Vacuum Cleaner | General interior cleaning | 180 | | 180 | | | |
| LS | Life Support System | General inspection | 30 | | | | | |
| | | 14 DAYS | | | | | | |
| LS 108 | Urine Filter | Replace filter (2) | 30 | | | | | |
| | | 30 DAYS | | | | | | |
| LS 38 | Evaporation Wick | Replace wick (4) | 60 | | | | | |
| LS 164 | Gas Chromatograph | Calibrate | | 20 | | | | |
| LS 165 | Mass Spectrometer | Calibrate | | 20 | | | | |
| LS | Life Support System | Check instrumentation, operate manual valves | 60 | | | | | |
| CS 25 | Vacuum Cleaner | Replace bag | | | 10 | | | |
| CS 26 | Fire Extinguishers | Inspect | | | 30 | | | |
| RE | Reentry System | Checkout† | | 60 | | | 60 | |
| ST | Structure | Inspect spacecraft exterior† | | | 120 | 120 | | 1,6,15,16,17 |
| IF 4,5 | Display Indicators | Replace lamp (2) | | 10 | | | | |

†Extravehicular activity (EVA) is required for all or part of these scheduled maintenance tasks.

Table 5.2-6: SCHEDULED MAINTENANCE---1985 $L_1$ LIBRATION CENTER MISSION (Cont)

| Code | Item | Task | Time/Skill (min) LS | EE | ME | ST | CM | Resources |
|---|---|---|---|---|---|---|---|---|
| LS 44 | Charcoal Filter, Gas | Replace filter (4) | 60 | | | | | 1,2 |
| LS 45 | Charcoal Filter, Fluid | Replace filter (4) | 80 | | | | | 1,2 |
| LS 77 | Charcoal and Particulate Filter | Replace filter (4) | 60 | | | | | 1,2 |
| LS 78 | Absolute Filter | Replace filter (2) | 30 | | | | | 1,2 |
| LS 87 | Catalytic Filter | Replace cartridge (4) | 80 | | | | | 1,2 |
| | | 90 DAYS | | | | | | |
| LS 43 | Conductivity Sensor | Calibrate (4) | | 80 | | | | 1,9 |
| LS 113 | Odor Filter | Replace filter (2) | 40 | | | | | 1,2 |
| LS 162 | $O_2$ Partial Pressure Sensor | Replace element (4) | 40 | | | | | 1 |
| LS 163 | $CO_2$ Partial Pressure Sensor | Replace element (4) | 40 | | | | | 1 |
| CS 17 | Film Viewer | Inspect and clean | | 15 | | | | 1,2 |
| CS 20 | Microfilm Reader | Inspect and clean | | 15 | | | | 1,2 |
| CS 33 | Lamp, Incandescent | Replace lamp | | 10 | | | | |
| CS 34 | Lamp, Fluorescent | Replace lamp (2) | | 40 | | | | |
| DM 6 | Typewriter | Inspect and clean | | 30 | | | | 1,2 |
| DM 8 | Console Viewer | Inspect and clean | | 15 | | | | 1,2 |
| DM 11 | Film Projector/Scanner | Inspect and clean | | 15 | | | | 1,2 |
| EX | Experiment Airlock | Lubricate mechanisms | | | 30 | | | 1,12 |
| RE | Reentry System | Extensive checkout*† | | 60 | | | 60 | 1,2 |
| RD | Docking System | Inspect and lubricate† | | | 90 | 90 | | 1,12,15,16 |

*The 30- and 90-day checkout will be integrated resulting in a total checkout time of 120 minutes.

†Extravehicular activity (EVA) is required for all or part of these scheduled maintenance tasks.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 360 DAYS | | | | | | |
| EP 5 | Voltage Regulator | Replace regulator | | 120 | | | | 1 |
| EP 7 | Battery Charge Regulator | Replace regulator | | 90 | | | | 1 |

Table 5.2-6: SCHEDULED MAINTENANCE---1985 $L_1$ LIBRATION CENTER MISSION (Cont)

| Code | Item | Task | Time/Skill (min) LS | EE | ME | ST | CM | Resources |
|---|---|---|---|---|---|---|---|---|
| | | 600 DAYS | | | | | | |
| LS 13 | Bosch Reactor | Replace catalyst (2) | 240 | 240 | | | | 1,2 |
| | | 720 DAYS | | | | | | |
| EP 2 | Battery | Replace battery | | 150 | 150 | | | 1,10 |
| DM 12 | Projection Lamp | Replace lamp | | 15 | | | | |
| PP 27 | Engine Assy, Attitude Control | Replace Engine assy (4)† | | | 720 | 720 | | 1,15,16 |
| PP 28 | Engine, Station Keeping | Replace engine (4)† | | | 720 | 720 | | 1,15,16 |
| | | 800 DAYS | | | | | | |
| EP 4 | Inverter | Replace inverter | | 80 | | | | 1 |
| | | RESUPPLY | | | | | | |
| LS 25 | Electrolysis Module | Replenish electrolyte (3) | 90 | | | | | 1 |
| LS 55 | Oxygen Tanks | Replenish oxygen (2) | 60 | | 60 | | | 1 |
| LS 56 | Nitrogen Tanks | Replenish nitrogen (2) | 60 | | 60 | | | 1 |
| LS 62 | Water Tanks | Replenish water | 30 | | 30 | | | 1 |
| LS 66 | Wash Water Chemical | Replenish chemical | 20 | | | | | 1 |
| LS 106 | Food Container | Replenish food | 180 | | 180 | | | |
| LS 112 | Feces Bags | Replenish bags | 30 | | | | | |
| PP | Propellants | Replenish propellants | | | 120 | 120 | | 1 |
| PP | Pressurants (Nitrogen) | Replenish pressurant | | | 120 | 120 | | 1 |
| CS | Clothing and Personal Items | Replenish supplies | | | 60 | | | |
| EV 2 | LiOH Canisters | Replenish canisters | 30 | | | | | |

†Extravehicular activity (EVA) is required for all or part of these scheduled maintenance tasks.

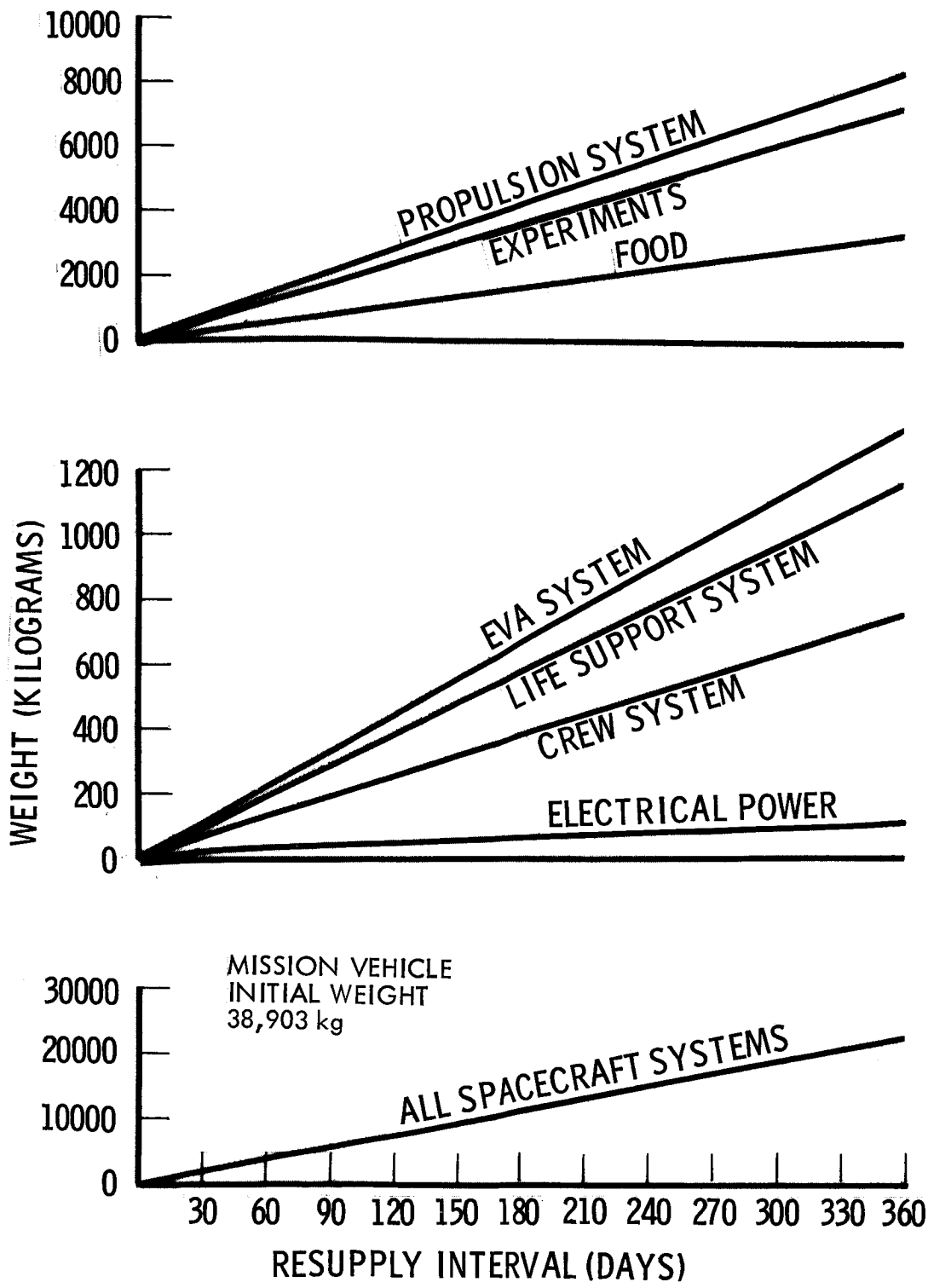


Figure 5.2-7: RESUPPLY AND EXPENDABLES REQUIREMENTS — 1985 $L_1$ Libration Center Mission

Table 5.2-8 summarizes the total and average man-minutes per day for the scheduled maintenance required at 1-, 7-, 14-, 30-, 60- and 90-day intervals for each subsystem. An average of about 114 man-minutes (1.9 manhours) per day are required through the 90-day period to accomplish the scheduled maintenance indicated. About 77% of this is attributed to the life support and crew systems; about 47% of this is caused by the weekly general interior cleaning function that was estimated to require two men for 3 hours (total of 6 manhours).

Table 5.2-9 shows a breakdown of the total and average man-minutes per day for each crew skill. The life support system skill is involved in 50% of the scheduled maintenance.

## 5.3 EFFECTS OF UNSCHEDULED MAINTENANCE ON OVERALL MISSION REQUIREMENTS

A mission simulation model (described in Section 3.4) was used to simulate the unscheduled maintenance requirements of the spacecraft and determine the effects of maintenance time, spares weight, resupply intervals, system reliability, and maintenance resources on the mission. The data presented in this study is based on 100 simulation runs of each mission time or resupply interval. By performing many runs, a broad and authoritative statistical base of expected unscheduled maintenance activities can be established. The figures and tables presented summarize the unscheduled maintenance requirements by crew skill and subsystem, the spares use rates, repair task time, daily repair time, airlock use, and spacesuit usage for each of the Earth-orbital missions.

### 5.3.1 1975 NEAR-EARTH ORBITAL MISSION

The mission simulation was conducted for mission times (resupply intervals) of 90, 120, 180 and 360 days. In each instance 100 simulation runs were made for each time interval. Therefore, for the 90-day mission time, the range of values and probability figures presented represent what could be expected in the equivalent of 25 years of operation. Similarly, the 100 simulations of the 360-day time period represent the expected statistics resulting from the equivalent of 100 years of operation. A 90-day resupply was assumed as a baseline and the statistics presented are for this mission unless stated otherwise.

Table 5.3-1 summarizes the unscheduled maintenance crew skill requirements for the 1975 near-Earth orbital mission. It indicates that the average number of days between requirements for a crew skill to perform unscheduled maintenance is 6.6 days and the average time that a given skill will be required is about 148 minutes. This results in a mean of about 22.5 minutes per day throughout the mission; that is, substantially less than 0.5 hour per day will be spent on unscheduled maintenance activities. This is a relatively insignificant workload and there should not be any problem integrating it with normal operation of the spacecraft. The life support system skill specialty will be required over 33% of the total time. Although the electrical/electronic skill is required most frequently (18.2 days between tasks, as a mean), the average time spent on each task is low, so the overall requirement for this skill amounts to about 24% of the total repair time.

Table 5.2-8: SUBSYSTEM SCHEDULED MAINTENANCE REQUIREMENTS--- 1985 $L_1$ LIBRATION CENTER MISSION

| Subsystem | Man-Minutes/Maintenance Interval (days) 1 | 7 | 14 | 30 | 60 | 90 | Average Man-Minutes/Day |
|---|---|---|---|---|---|---|---|
| Life Support | 10 | 60 | 30 | 160 | 310 | 200 | 33.4 |
| Crew System | | 360 | | 40 | | 80 | 53.8 |
| Inflight Test | 10 | | | 10 | | | 10.3 |
| Reentry System | | | | 120 | | 120 | 5.3 |
| Structure | | | | 240 | | | 8.0 |
| Rendezvous and Docking | | | | | | 180 | 2.0 |
| Data Management | | | | | | 60 | 0.7 |
| Experiment | | | | | | 30 | 0.3 |
| Total Man-Minutes | 20 | 420 | 30 | 570 | 310 | 670 | |
| Average Man-Minutes/Day | 20 | 60 | 2.1 | 19 | 5.2 | 7.5 | 113.8 |

NOTE: Scheduled maintenance required at intervals greater than 90 days and at the resupply periods are not shown in the above summary as these tasks must be done at about the time indicated and cannot realistically be apportioned over a number of days.

Table 5.2-9: SCHEDULED MAINTENANCE CREW SKILL REQUIREMENTS--- 1985 $L_1$ LIBRATION CENTER MISSION

| Crew Skill | Man-Minutes/Maintenance Interval (days) 1 | 7 | 14 | 30 | 60 | 90 | Average Man-Minutes/Day |
|---|---|---|---|---|---|---|---|
| Life Support Systems | 10 | 240 | 30 | 120 | 310 | 120 | 56.9 |
| Electrical/Electronic | 10 | | | 110 | | 280 | 16.8 |
| Mechanical | | 180 | | 160 | | 120 | 32.4 |
| Structures | | | | 120 | | 90 | 5.0 |
| Communications | | | | 60 | | 60 | 2.7 |
| Total Man-Minutes | 20 | 420 | 30 | 570 | 310 | 670 | |
| Average Man-Minutes/Day | 20 | 60 | 2.1 | 19 | 5.2 | 7.5 | 113.8 |

NOTE: Scheduled maintenance required at intervals greater than 90 days and at the resupply periods are not shown in the above summary as these tasks must be done at about the time indicated and cannot realistically be apportioned over a number of days.

Table 5.3-1: UNSCHEDULED MAINTENANCE CREW SKILL REQUIREMENTS---
1975 NEAR-EARTH ORBITAL MISSION

| Crew Skill | Percent of Total Repair Time | Mean Days Between Skill Use | Average Minutes/ Skill Use | Average Minutes/ Day |
|---|---|---|---|---|
| Life Support Systems | 33.8 | 21.0 | 160 | 7.6 |
| Electrical/Electronic | 24.4 | 18.2 | 100 | 5.5 |
| Mechanical | 14.2 | 51.3 | 164 | 3.2 |
| Structures | 4.5 | 262.0 | 262 | 1.0 |
| Communications | 5.8 | 72.2 | 94 | 1.3 |
| Guidance and Control | 17.3 | 82.0 | 322 | 3.9 |
| Totals | 100.0 | 6.6 | 148 | 22.5 |

NOTE: The above data is based on 100 ninety-day simulation runs, which is the equivalent of 25 years of operation.

Table 5.3-2 summarizes the unscheduled maintenance requirements by subsystem. The life support subsystem accounts for about 45% of both the total system failures and repair time. The inflight test subsystem accounts for about 19% of the failures but only 11% of the repair time, because of the relatively low repair time per task. The total average minutes per day shown here are less than those given in the previous table because this table reflects the elapsed repair time, whereas table 5.3-1 is affected by the fact that two crew skills are required for some maintenance tasks. Figure 5.3-3 graphically portrays the contribution of each subsystem to the total failures and repair time.

In the simulation, it was assumed there was only one of each type of skill available, two basic maintenance tool kits available, and one of each other maintenance resource available. The only queuing that occurred, during the 100 ninety-day runs, was once for 66 and 132 minutes, respectively, for an EE skill and a guidance and control skill (GC). For the 180-day simulation the queuing only increased slightly; four times for an EE skill at an average of 188 minutes, once for a GC skill for 132 minutes, and once for a maintenance tool kit for 24 minutes. To determine what the impact on the maintenance resources would be if a higher incidence of failures occurred, another 100 ninety-day simulations were made while assuming twice the basic system failure rate. A total of 15 instances of queuing occurred at an overage of 137 minutes each. The 15 queues occurred over the total 100 simulation runs or the equivalent of 25 years of operation. Therefore, even at an assumed higher-than-expected failure rate, a crew complement of one of each type skill level should be sufficient to support any unscheduled maintenance requirements. Queuing statistics were tabulated separately during the simulation runs; therefore, the average minutes per task or failure shown in these charts does not include any queuing time.

Previously, in Section 5.1, the curves shown depicted what weight must be added to the basic spacecraft system to achieve a desired probability of crew survival and mission success. The mission simulation was used to predict how much of the added weight will actually be used as spares to correct random component failures.

Figure 5.3-4 presents the expected spares weight usage for 90- and 180-day resupply intervals. Figure 5.3-5 presents the same data for 120 and 360 days. As mentioned previously, each curve represents 100 simulations of each time interval. A summary of the data shown in the figures is presented in the following table in terms of percentages of the initial weight added to the system for a 0.99 $P_{MS}$. The spares usage data is based on replacing all failures in the basic system, plus the identified parallel and standby redundancy requirements. The parallel redundant items were assumed to operate the same amount of time as the basic item. The nonoperating failure rate was assumed for the standby redundant items.

Table 5.3-2: SUBSYSTEM UNSCHEDULED MAINTENANCE REQUIREMENTS---
1975 NEAR-EARTH ORBITAL MISSION

| Subsystem | Percent of Total System Failures | Percent of Total System Repair Time | Mean Days Between Failures | Average Minutes/ Task | Average Minutes/ Day |
|---|---|---|---|---|---|
| Life Support | 45.96 | 44.02 | 15 | 141 | 9.4 |
| Communications | 7.03 | 4.41 | 97 | 95 | 1.0 |
| Crew System | 0.15 | 0.01 | 4500 | 14 | 0.0 |
| Data Management | 6.20 | 16.94 | 110 | 401 | 3.6 |
| Electrical Power | 1.36 | 2.63 | 500 | 284 | 0.6 |
| Experiment | 0.00 | --- | --- | --- | --- |
| Extravehicular Activity | 0.60 | 1.43 | 1130 | 348 | 0.3 |
| Inflight Test | 18.90 | 10.76 | 36 | 84 | 2.3 |
| Maintenance Equipment | 0.00 | --- | --- | --- | --- |
| Propulsion | 2.57 | 4.55 | 265 | 260 | 1.0 |
| Reentry System | 0.08 | 0.03 | 9000 | 62 | 0.0 |
| Rendezvous and Docking | 2.04 | 1.79 | 333 | 129 | 0.4 |
| Stability and Control | 15.04 | 13.16 | 45 | 129 | 2.9 |
| Structure | 0.08 | 0.26 | 9000 | 513 | 0.1 |
| Totals | 100.00 | 100.00 | 6.8 | 147 | 21.6 |

NOTE: The above data is based on one-hundred 90-day simulation runs, which is the equivalent of 25 years of spacecraft operation.

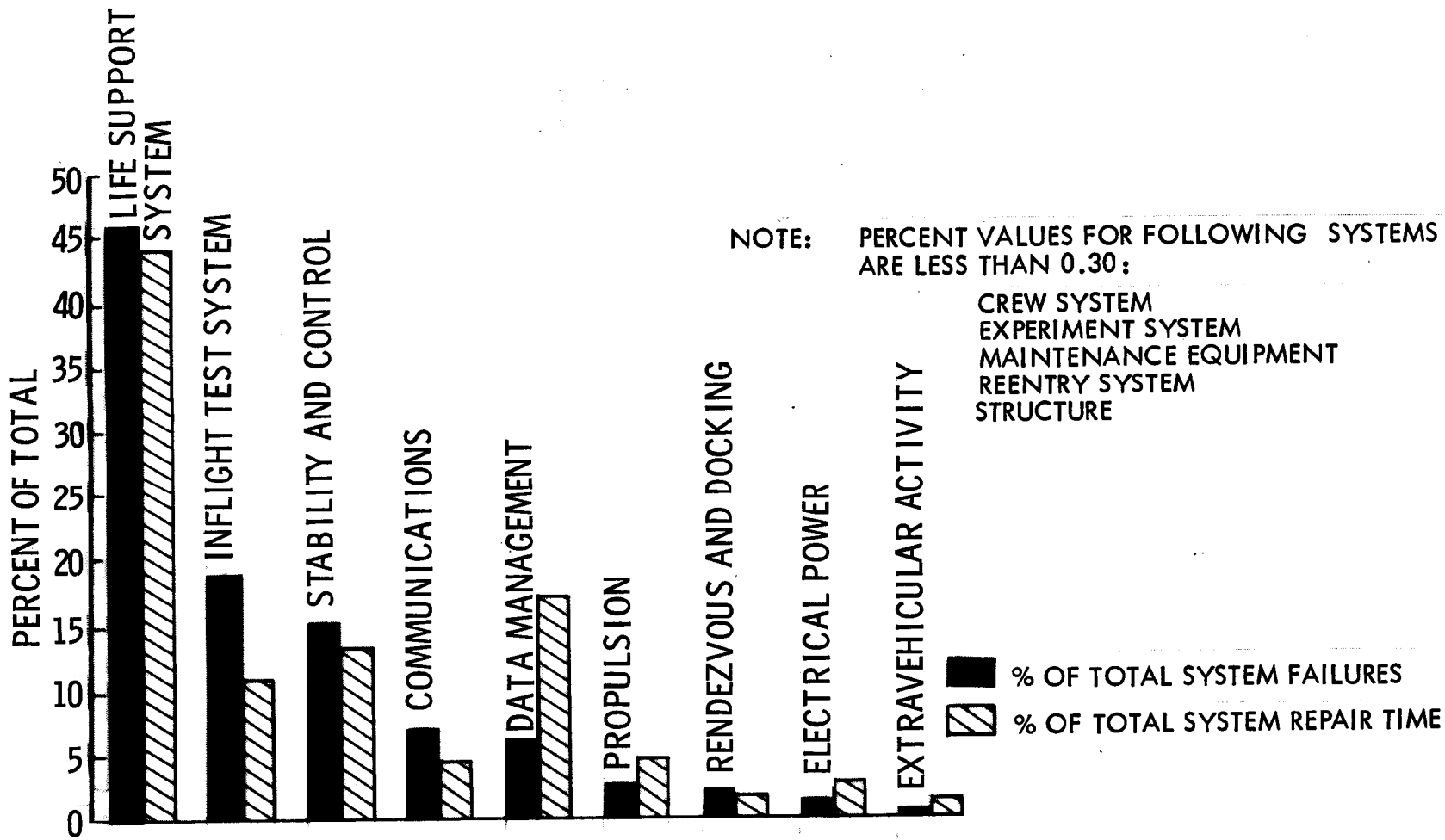


Figure 5.3-3: SUBSYSTEM FAILURES AND UNSCHEDULED MAINTENANCE REPAIR TIME — 1975 Near-Earth Orbit Mission

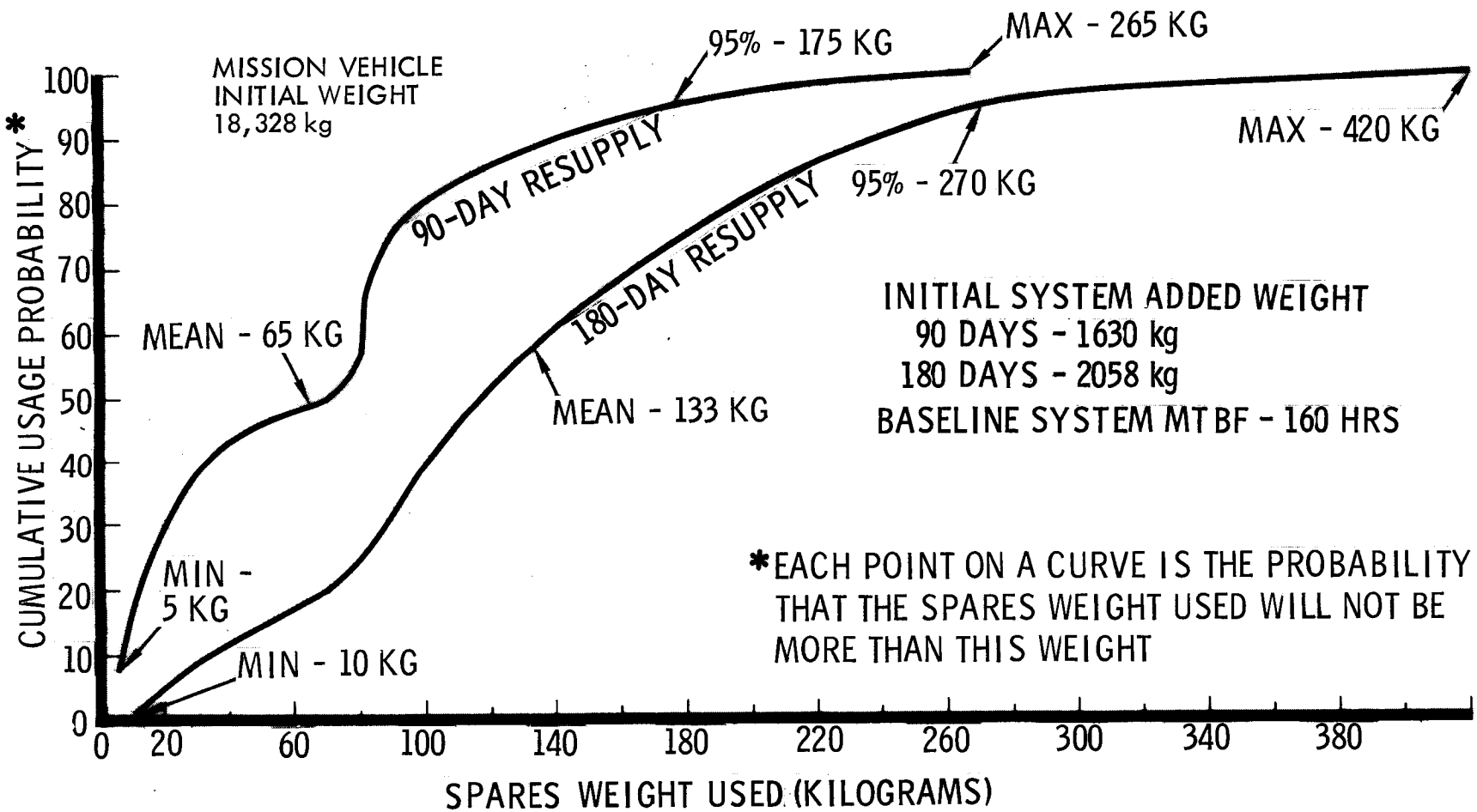


Figure 5.3-4: SPARES WEIGHT USAGE PROBABILITY -90 AND 180-DAY RESUPPLY PERIODS — 1975 Near-Earth Orbit Mission

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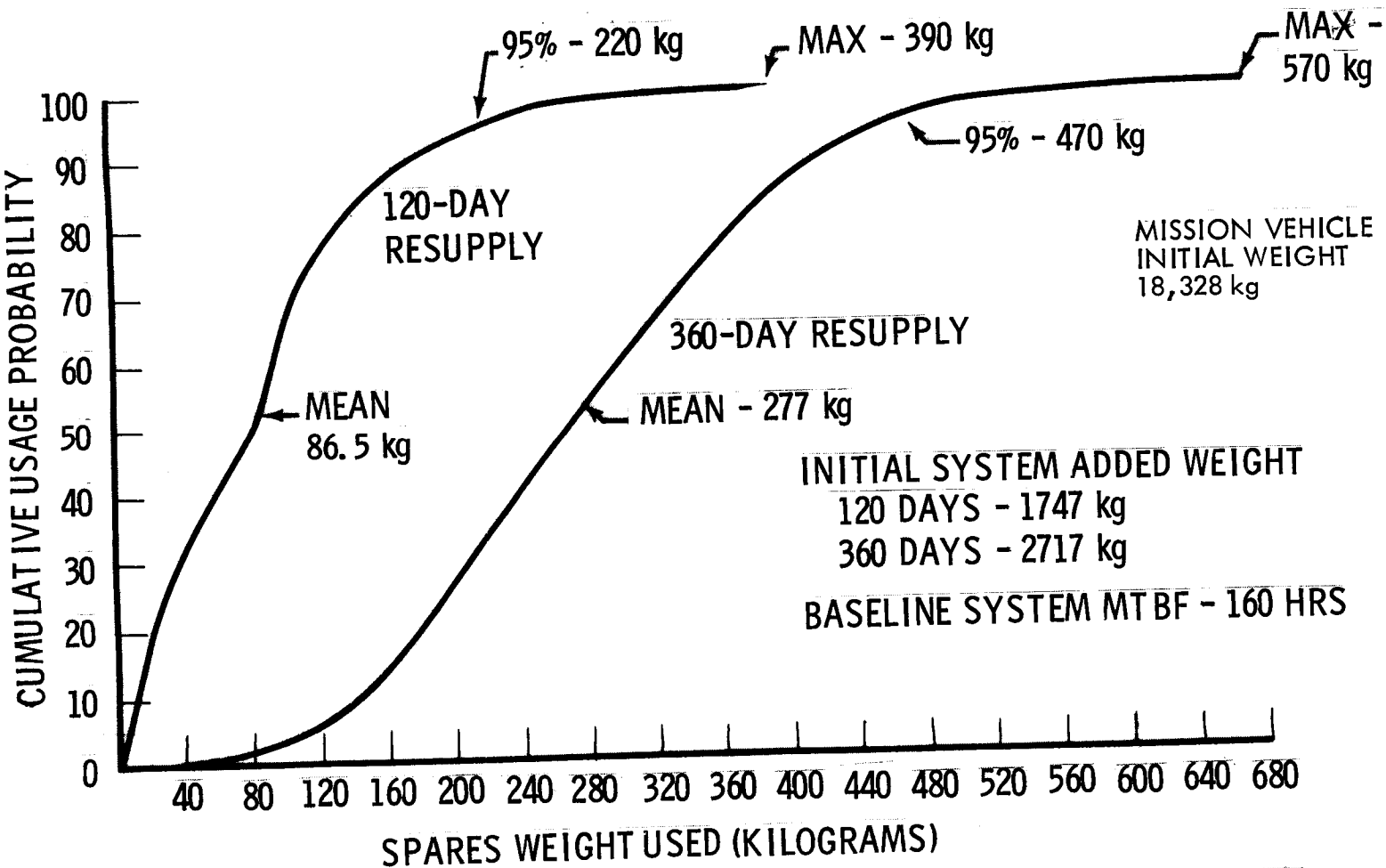


Figure 5.3-5: SPARES WEIGHT USAGE PROBABILITY — 120- AND 360-DAY RESUPPLY PERIODS — 1975 Near-Earth Orbit Mission

PREDICTED SPARES USAGE

| Resupply Interval | Initial Added Wt-kg (0.99$P_{MS}$) | Spares Weight Used---kg (% Initial Wt) Minimum | Mean | Maximum |
|---|---|---|---|---|
| 90 days | 1630 | 5 (0.3) | 65 (4.0) | 265 (16.3) |
| 120 days | 1747 | 5 (0.3) | 87 (5.0) | 390 (22.3) |
| 180 days | 2058 | 10 (0.5) | 133 (6.5) | 420 (20.4) |
| 360 days | 2717 | 40 (1.5) | 277(10.0) | 570 (21.0) |

Therefore, on each 90-day logistics resupply mission it is expected that an average spares weight of 65 kilograms will be required. However, because there is a statistical possibility that up to 265 kilograms must be resupplied, allowance for this much weight must be included in the logistics resupply mission planning. Another use of the data is the maximum expected spares usage for 360 days is 570 kilograms. Therefore, if the expected maximum of 265 kilograms is used for one 90-day interval, the maximum usage to be expected over the next three 90-day intervals (270 days) is 570 minus 265 or 305 kilograms. The table shows that the longer the resupply interval, the higher the percentage of spares weight used, which means that usage of the spares provided was more efficient. The bulge in the curves was caused by the few relatively heavy items in the system. When none of these are used, the weight is low, but increases rapidly when heavy items are used. As the resupply interval increases, the probability of using some heavy items during any one interval increases and the curve smooths out. Figure 5.3-6 graphically portrays what spares weight in orbit was initially provided and what the range in expected usage was for the different resupply intervals. Figure 5.3-7 shows the spares volume used for 90-, 120-, 180- and 360-day resupply intervals.

Figure 5.3-8 portrays the daily repair time distribution for unscheduled maintenance resulting from the system failures that occurred in the simulation. On 86.2% of the days there will be no requirement for unscheduled maintenance; on 3.56% of the days between 1 to 30 man-minutes of maintenance will be required. The mean daily repair time would be about 23 man-minutes assuming the maintenance could be distributed over all the days. The maximum repair time is 2400 man-minutes. However, on only 3% of days will more than 200 man-minutes be required. This repair time data was based on the mean-time-to-repair determined for each component during the maintenance task analysis and is the same as the MTTR value used in the MARCEP program. To more accurately simulate the real life situation where a task may take much less or more time than expected, the MTTR values entered into the simulation program were multiplied by a value randomly picked from a cumulative distrubution of a log normal curve. This resulted in the actual repair times varying from 0.1 to 10.0 times the expected MTTR, with about 36% of the repair times being within the range of -0.5 to +0.5 of the basic MTTR.

Figure 5.3-9 represents the repair task-time distribution for 14% of the days during which some repair was required. This chart shows that 18.3% of the tasks will require from 21 to 40 minutes, and 50% of the tasks require less than 70 minutes. However, the mean task time was about 147 minutes due

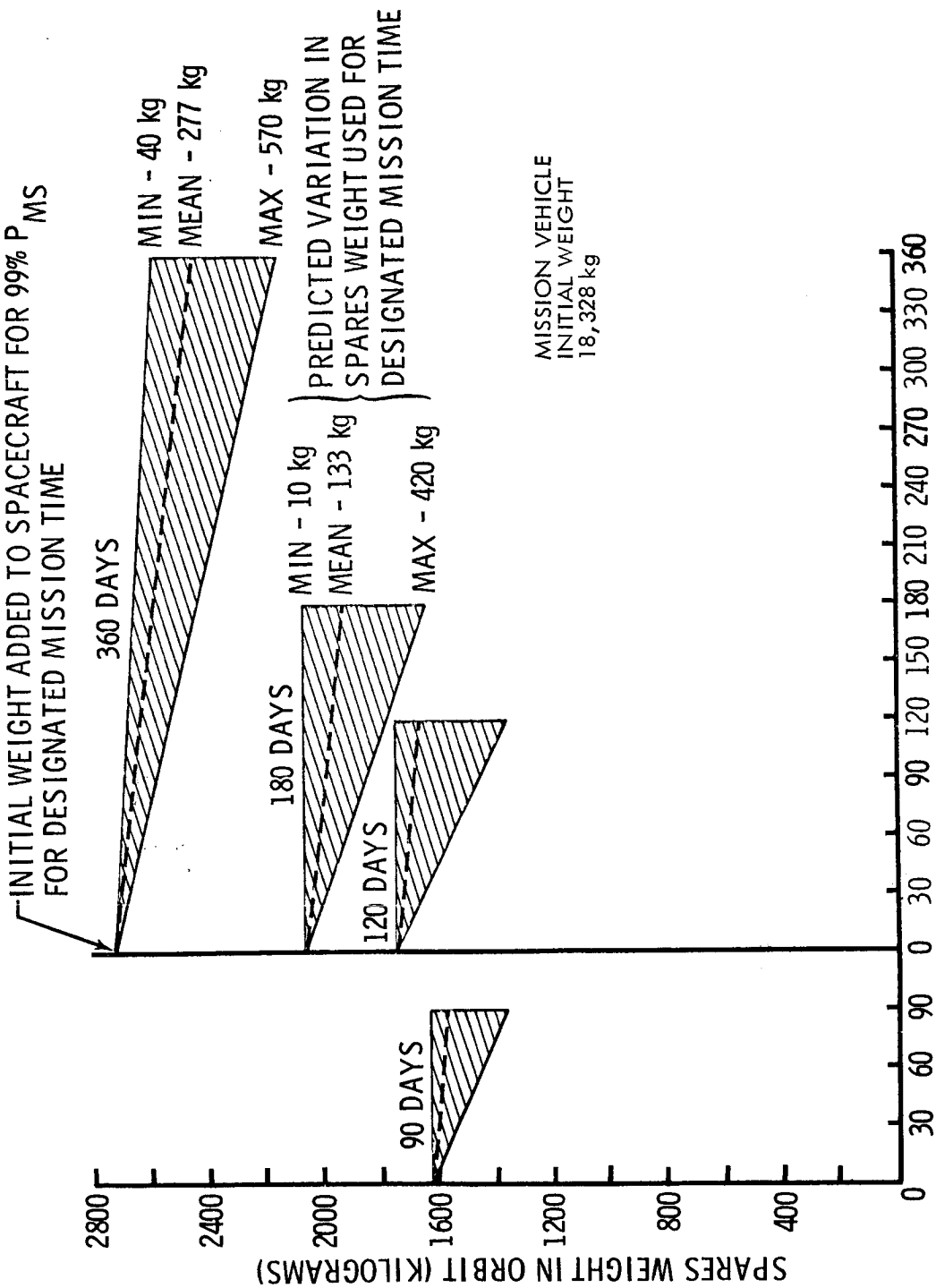


Figure 5.3-6: RANGES OF SPARES WEIGHT USAGE — 90-, 120-, 180-, AND 360-DAY RESUPPLY PERIODS —1975 Near-Earth Orbit Mission

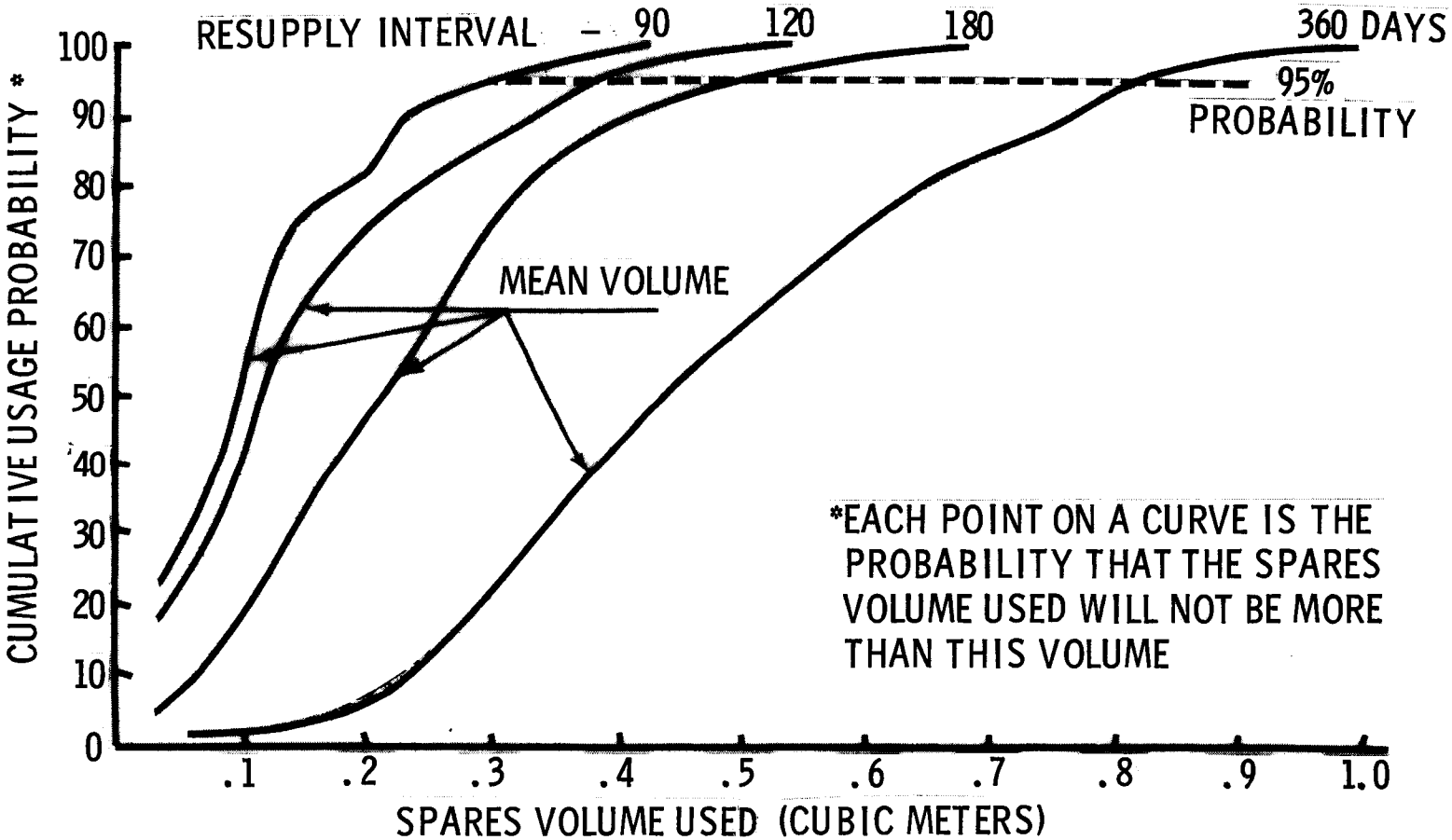


Figure 5.3-7: SPARES VOLUME USAGE PROBABILITY — 90-, 120-, 180-, AND 360-DAY RESUPPLY PERIODS — 1975 Near-Earth Orbit Mission

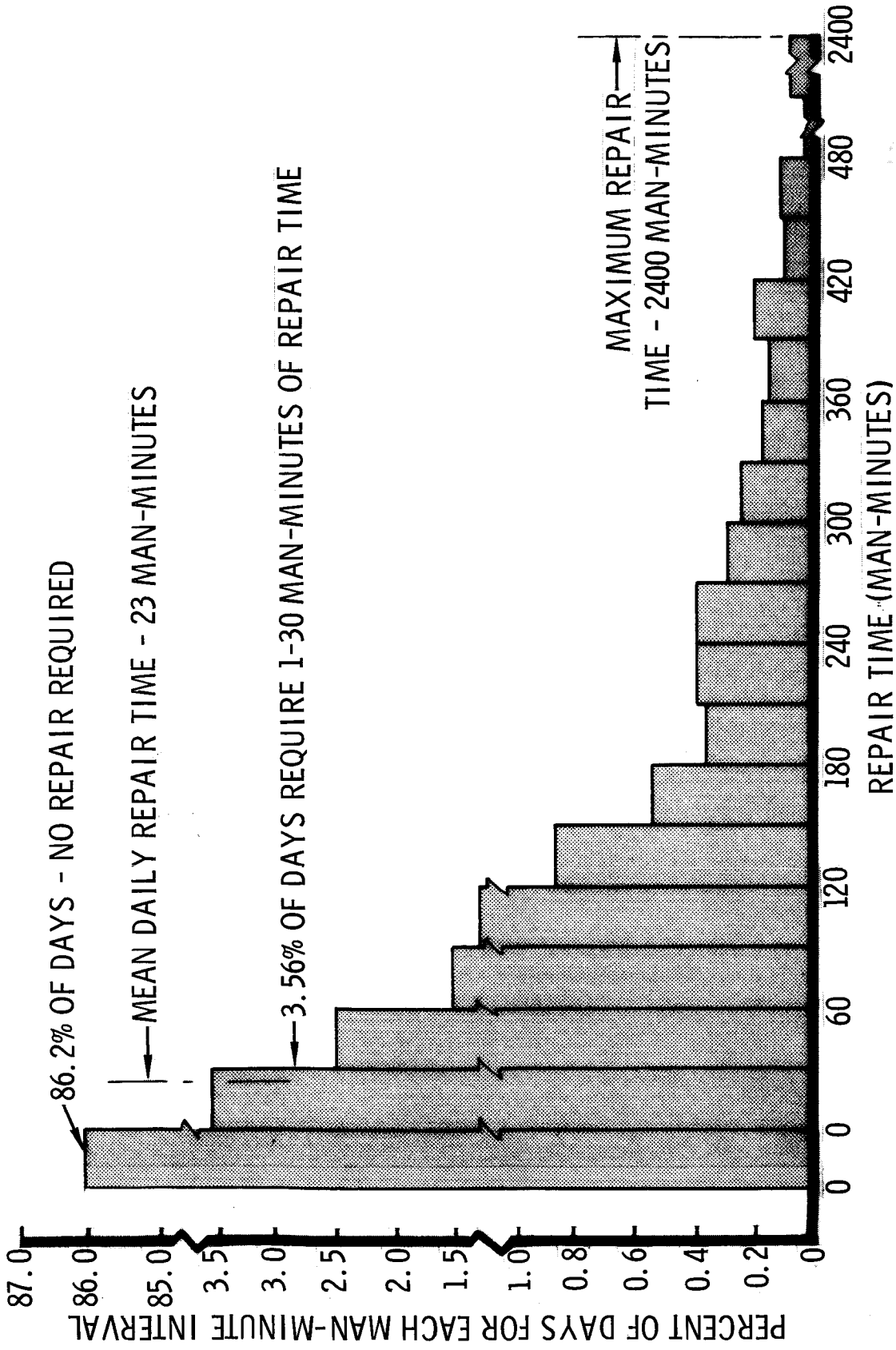


Figure 5.3-8: UNSCHEDULED MAINTENANCE DAILY REPAIR TIME DISTRIBUTION — 1975 Near-Earth Orbit Mission



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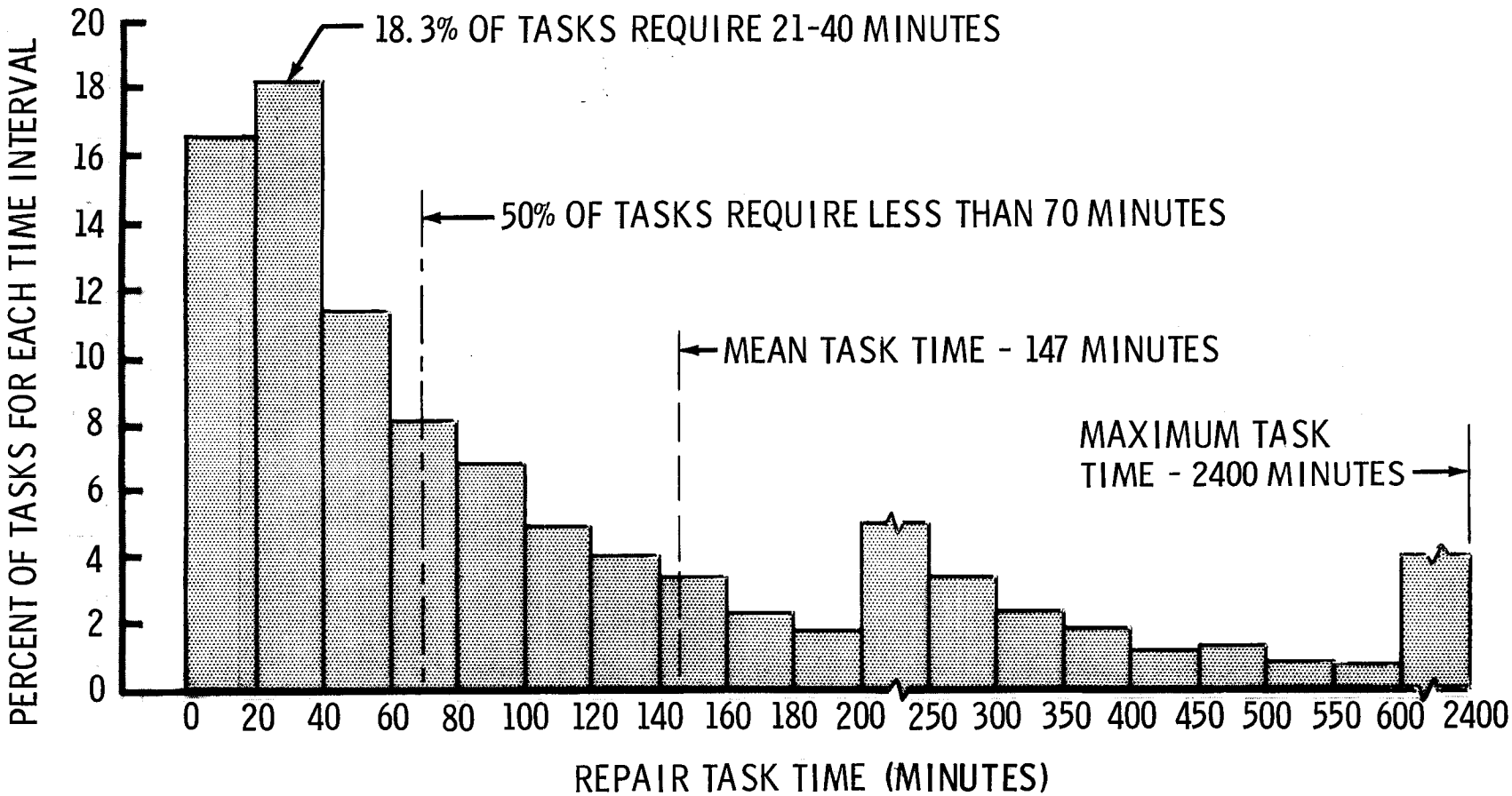


Figure 5.3-9: UNSCHEDULED MAINTENANCE REPAIR TASK TIME DISTRIBUTION — 1975 Near-Earth Orbit Mission

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to the effect of a few repairs that require a large amount of time. Approximately 90% of the tasks will take less than 360 minutes or 6 hours. The simulations for 180-day resupply intervals resulted in a mean task time of 152 minutes.

Analyses of the effects of failure rate differences on required maintenance time were also conducted. The results of the computer simulation indicated that doubling the failure rate would double the average daily maintenance time. The same increase in failure rate, however, increased the mean task time by approximately 3% and increased the 95 percentile task times by approximately 5%.

Figure 5.3-10 shows the number of airlock uses during a 90-day resupply interval for performing unscheduled maintenance. One airlock use was assumed to be one complete cycle as required for each extravehicular activity (EVA) task. A maximum stay-time of 3 hours was assumed for EVA, so that one airlock cycle was required for every 3 hours, or portion thereof, of the task. This graph shows that during 66% of the 90-day intervals there was no unscheduled maintenance task that required EVA and associated airlock use. On the average, a little less than one airlock use was required every 90 days for unscheduled maintenance, and the maximum expected airlock usage was 11 times during any one 90-day period, which occurred during one of the 100 runs. This represents a 1% probability of 11 airlock uses being required during any one 90-day interval. For comparison, the data for 180-day intervals was: 45% of the intervals require no airlock usage, the average was 1.6 uses every 180 days, and the maximum was 12 uses.

In conjunction with EVA for unscheduled maintenance, the manhours of spacesuit use were recorded. This data is shown in Figure 5.3-11. It was assumed that all EVA tasks required at least two men. Again, 66% of the 90-day intervals did not require EVA and therefore the use of spacesuits. The mean usage was 3.9 manhours per 90-day interval, with a maximum of 61 manhours that occurred on one of the 100 runs. For the 180-day runs, the mean was 7.2 and the maximum 65 manhours.

### 5.3.2 1985 $L_1$ LIBRATION CENTER MISSION

The 1985 mission simulation was performed for resupply intervals of 180 and 360 days. The baseline mission was assumed to have a 180-day resupply interval; therefore, the charts shown are generally for 180 days. Comments are made where differences were noted for a 360-day resupply interval. For each resupply interval 100 simulation runs were made.

Table 5.3-12 summarizes the unscheduled maintenance crew skill requirements. The mean days between skill use (8.5), the average minutes per skill use (138), and the average minutes per day (16.2) are all lower for this mission than for the 1975 baseline mission. The life support system, electrical/electronic, and mechanical skills account for about 30%, 27%, and 22%, respectively, of the total repair time, but for any one skill the average is less than 5 minutes per day. Again, this workload is relatively insignificant.

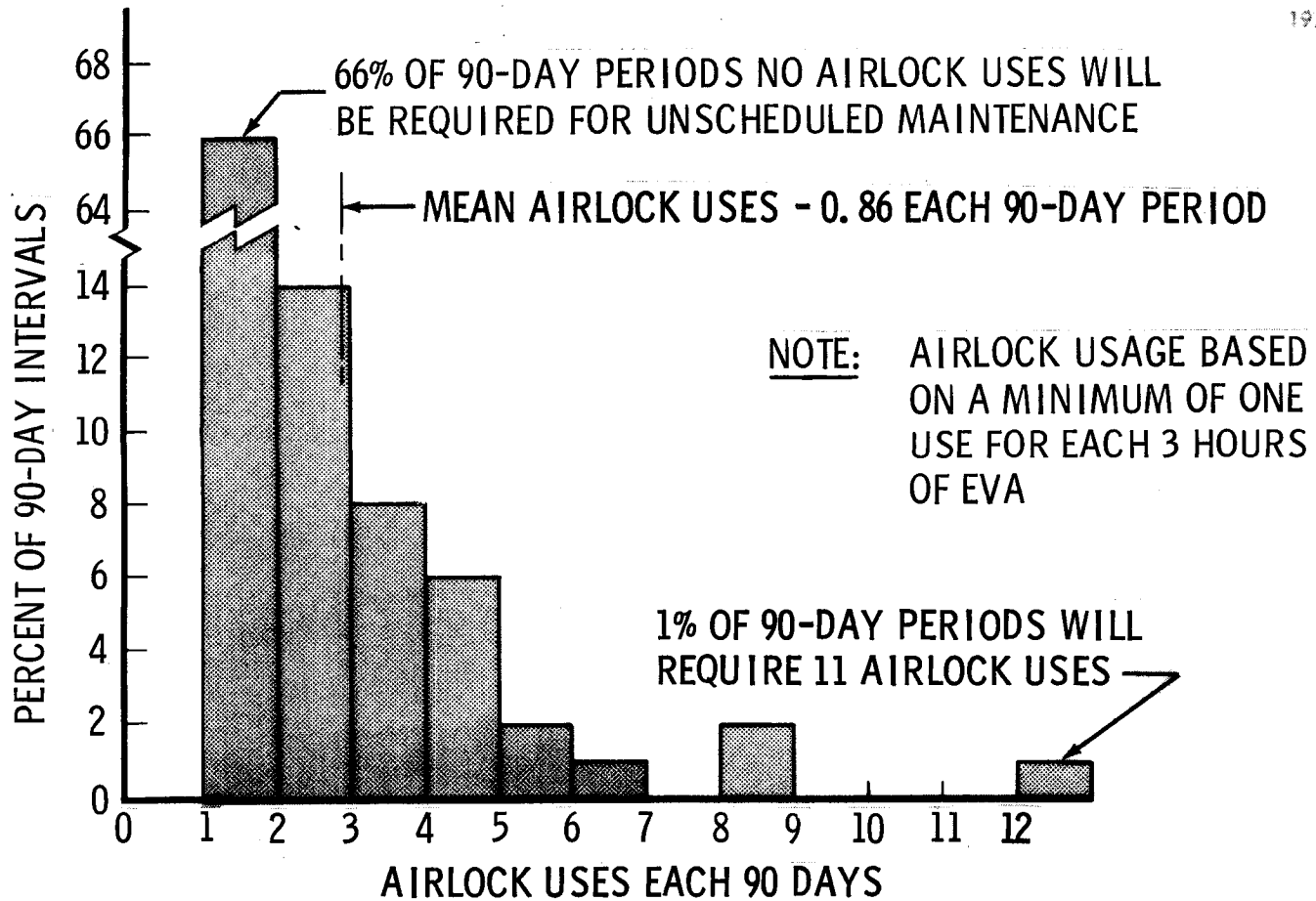


Figure 5.3-10: UNSCHEDULED MAINTENANCE AIRLOCK USAGE DISTRIBUTION — 1975 Near-Earth Orbit Mission

NOTE: SPACESUIT USE IS BASED ON TWO MEN BEING REQUIRED FOR ALL EVA TASKS

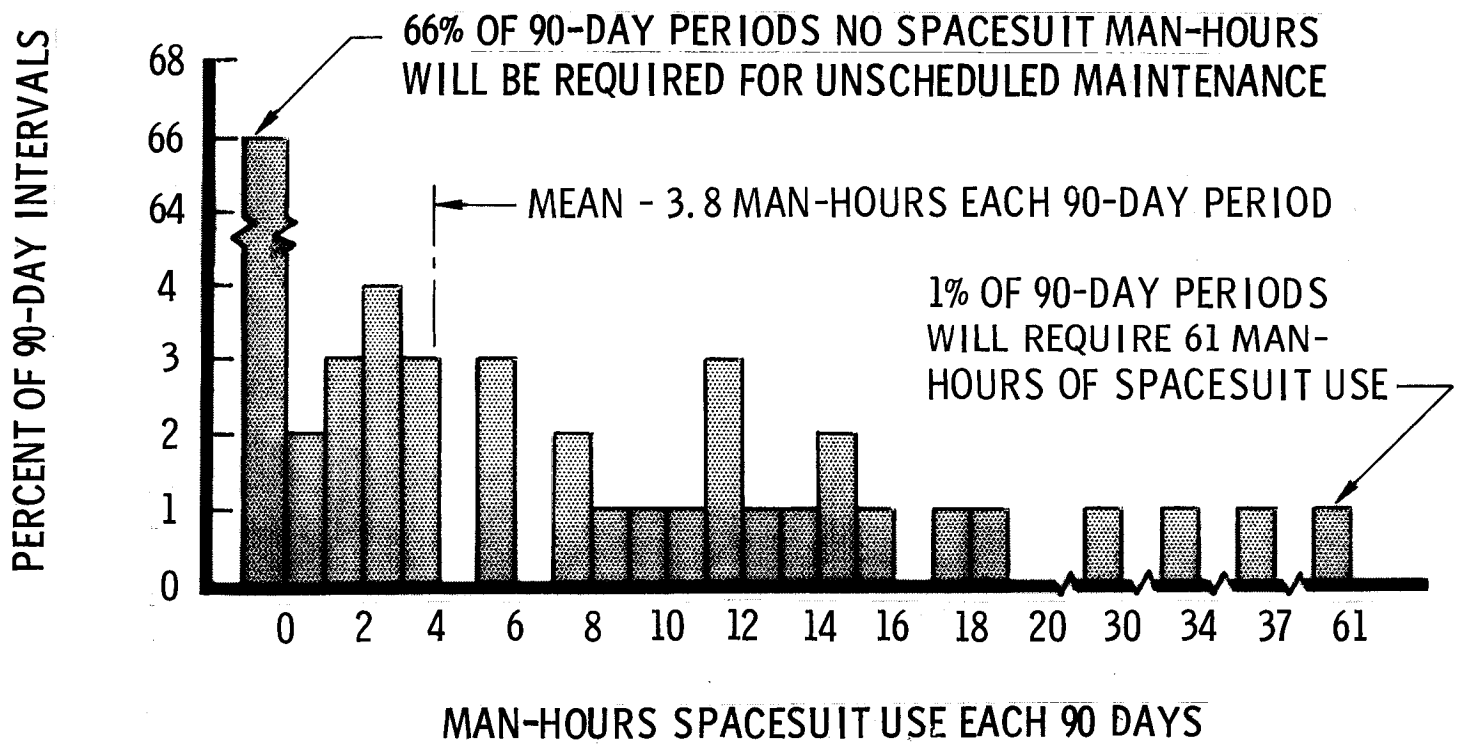


Figure 5.3-11: UNSCHEDULED MAINTENANCE SPACE SUIT USAGE DISTRIBUTION — 1975 Near-Earth Orbit Mission

Table 5.3-12: UNSCHEDULED MAINTENANCE CREW SKILL REQUIREMENTS--- 1985 $L_1$ LIBRATION CENTER MISSION

| Crew Skill | Percent of Total Repair Time | Mean Days Between Skill Use | Average Minutes/ Skill Use | Average Minutes/ Day |
|---|---|---|---|---|
| Life Support Systems | 30.2 | 32.2 | 156 | 4.9 |
| Electrical/Electronic | 27.2 | 25.0 | 110 | 4.4 |
| Mechanical | 21.6 | 57.5 | 200 | 3.5 |
| Structures | 10.5 | 160.0 | 267 | 1.7 |
| Communications | 4.3 | 167.0 | 113 | 0.7 |
| Guidance and Control | 5.0 | 190.0 | 153 | 0.8 |
| Medical | 0.4 | 3000.0 | 215 | 0.07 |
| Scientist---Experiments | 0.8 | 2225.0 | 294 | 0.13 |
| Totals | 100.0 | 8.5 | 138 | 16.2 |

NOTE: The above data is based on one hundred 180-day simulation runs, which is the equivalent of 50 years of operation.

Table 5.3-13 summarizes the unscheduled maintenance requirements by subsystem. Again, the life support subsystem accounts for the major workload, 42% of the total. The inflight test subsystem, while creating 25% of the failures, only accounts for 16% of the repair time. The statistics for the subsystems indicate some variations from the 1975 mission, but in general they compare favorably.

Figure 5.3-14 illustrates the expected spares weight use for 180- and 360-day resupply periods. The maximum expected use for 360 days is 150 kilograms. Therefore, if the expected maximum of 120 kilograms is used for one 180-day interval, the expected maximum use for the next 180 days should not be over 30 kilograms (150 minus 120). A summary of the data shown in the figure, in terms of a percent of the initial weight added to the system for a 99% probability of mission success, is presented in the table below.

PREDICTED SPARES USAGE

| Resupply Interval | Initial Added Wt-kg (0.99 $P_{MS}$) | Spares Weight Used---kg (% initial weight) | | |
|---|---|---|---|---|
| | | Minimum | Mean | Maximum |
| 180 days | 1489 | 10 (0.7) | 27 (1.8) | 120 (8.1) |
| 360 days | 1861 | 20 (1.1) | 55 (3.0) | 150 (8.1) |

These values in all cases are considerably less, both in terms of weight and percentage of initial weight, than that shown for the 1975 mission. Again, this is a result of the improvements in component reliability and component weight that were assumed for the 1985 time period. As noted in Figure 5.3-14, the system MTBF for the 1985 mission is 248 hours, compared with 160 hours for the 1975 mission. The added system weight of 1489 kilograms compares with 2058 kilograms for the 1975 mission 180-day resupply interval.

Figure 5.3-15 shows the distribution that can be expected of repair times on a daily basis. On 90.5% of the days of the mission there will be no repair actions required because of unscheduled failures and on 4.1% of the days, 1 manhour or less will be required. The mean daily repair time will be about 0.27 manhour. On only 3% of the mission days will the unscheduled maintenance time exceed 2.5 manhours. The statistics for the 360-day resupply period compared very closely with 0.3%.

Figure 5.3-16 shows the distribution of the repair task times for 9.5% of the days on which unscheduled maintenance is expected to be required. This chart indicates that most of the tasks, about 26.2%, will require 30 minutes or less. The mean task time is 2.3 hours, 67% of the unscheduled maintenance tasks will require 2 hours or less, and 95% will require less than 9 hours. The 360-day simulations resulted in a mean repair time of 2.25 hours.

Figure 5.3-17 presents the number of airlock uses expected during any one 180-day interval. It points out that 28% of the 180-day periods will require no airlock use for unscheduled maintenance; the maximum airlock use that occurred 1% of the time is between 20 and 25 for any one 180-day period. The statistics for the 360-day simulations show 14% of the time no airlock use is

Table 5.3-13: SUBSYSTEM UNSCHEDULED MAINTENANCE REQUIREMENTS---
1985 $L_1$ LIBRATION CENTER MISSION

| Subsystem | Percent of Total System Failures | Percent of Total System Repair Time | Mean Days Between Failures | Average Minutes/ Task | Average Minutes/ Day |
|---|---|---|---|---|---|
| Life Support | 42.96 | 41.91 | 25 | 135 | 5.40 |
| Communications | 4.47 | 3.24 | 225 | 100 | 0.45 |
| Crew System | 0.56 | 0.18 | 1,800 | 45 | 0.02 |
| Data Management | 3.02 | 3.07 | 334 | 141 | 0.42 |
| Electrical Power | 1.12 | 1.42 | 900 | 176 | 0.20 |
| Experiment | 1.12 | 2.80 | 900 | 347 | 0.39 |
| Extravehicular Activity | 0.34 | 2.12 | 3,000 | 877 | 0.29 |
| Inflight Test | 25.03 | 15.81 | 40 | 87 | 2.17 |
| Maintenance Equipment | 0.00 | 0.00 | --- | --- | --- |
| Propulsion | 6.09 | 11.85 | 165 | 269 | 1.63 |
| Reentry System | 0.56 | 1.29 | 1,800 | 318 | 0.18 |
| Rendezvous and Docking | 1.56 | 1.88 | 644 | 166 | 0.26 |
| Stability and Control | 11.73 | 13.29 | 86 | 157 | 1.82 |
| Structure | 0.06 | 0.02 | 18,000 | 43 | 0.00 |
| Navigation and Guidance | 1.40 | 1.12 | 720 | 111 | 0.16 |
| Totals | 100.00 | 100.00 | 10.03 | 138 | 13.40 |

NOTE: The above data is based on one-hundred 180-day simulation runs, which is the equivalent of 50 years of operation.

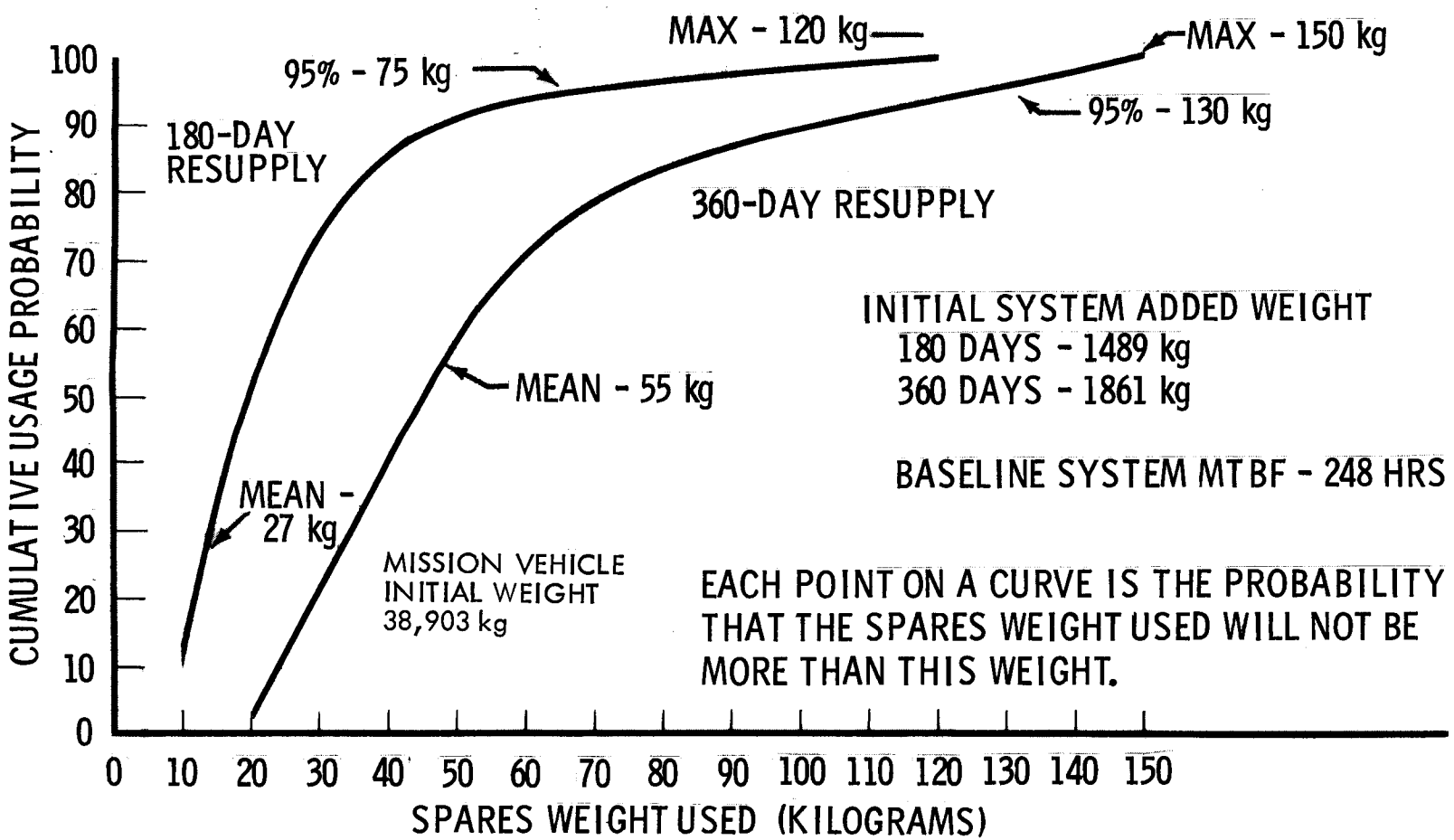


Figure 5.3-14: SPARES WEIGHT USAGE PROBABILITY — 180- AND 360-DAY RESUPPLY PERIODS — 1985 $L_1$ Libration Center Mission

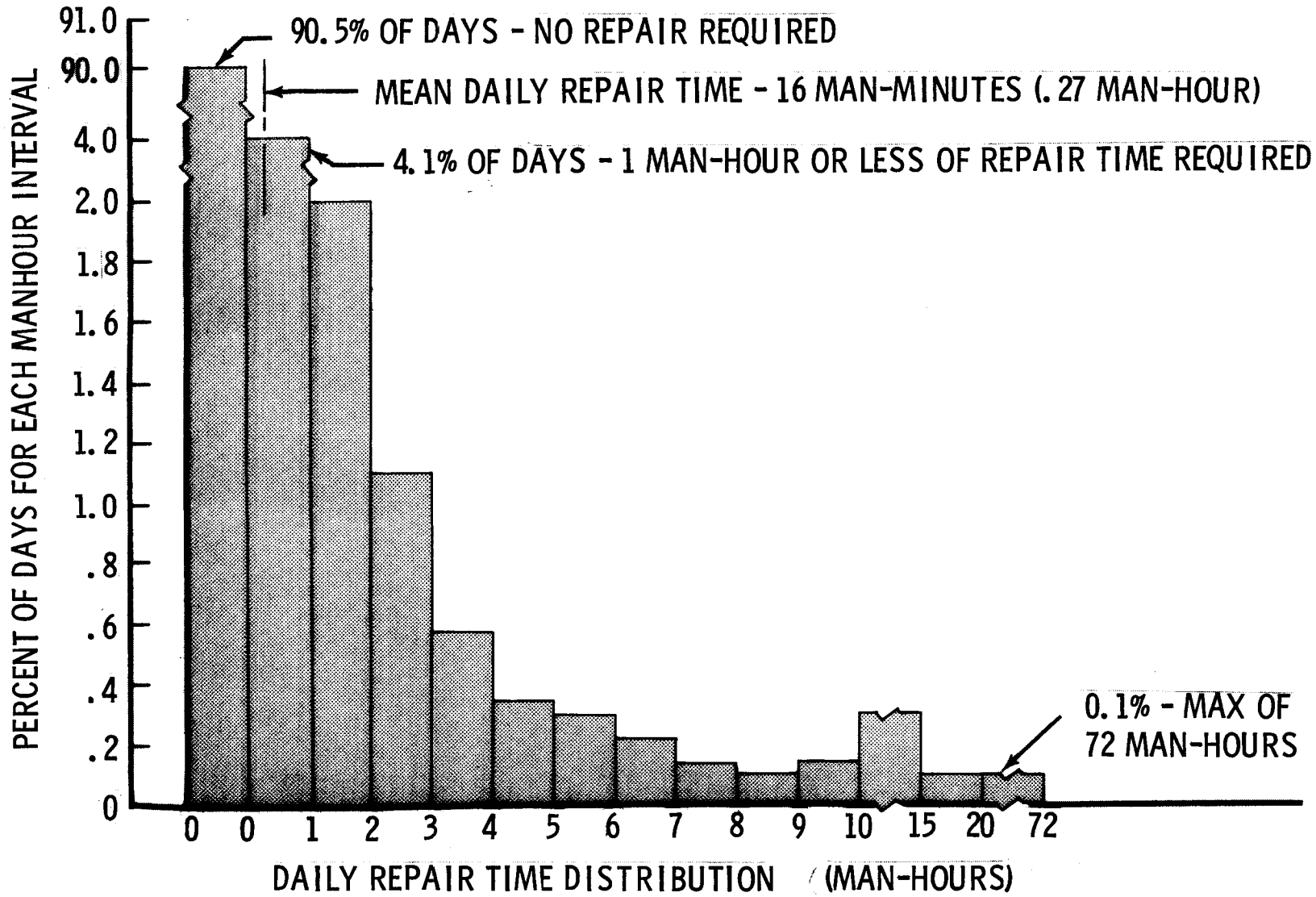


Figure 5.3-15: UNSCHEDULED MAINTENANCE DAILY REPAIR TIME DISTRIBUTION — 1985 $L_1$ Libration Center Mission

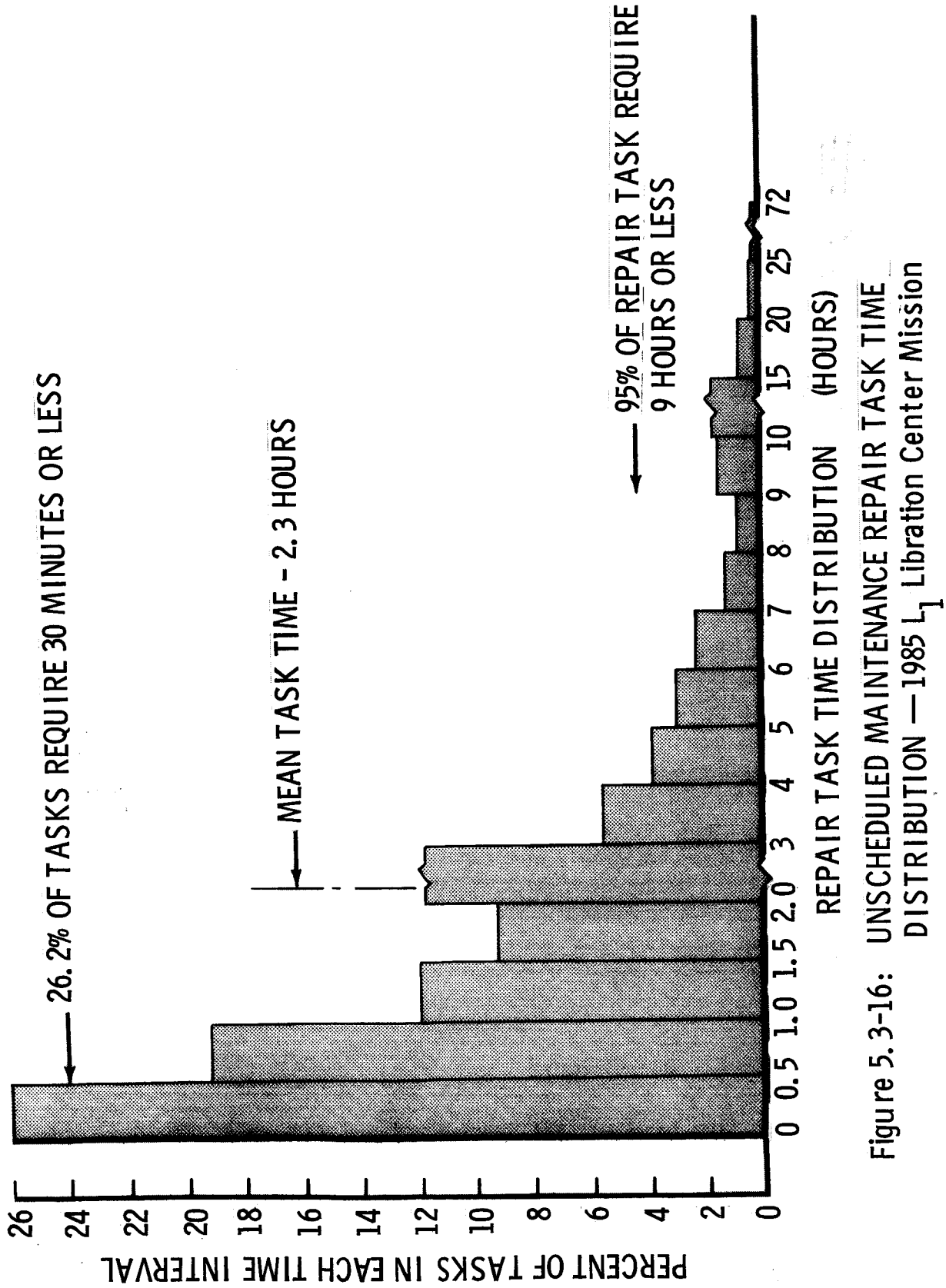


Figure 5.3-16: UNSCHEDULED MAINTENANCE REPAIR TASK TIME DISTRIBUTION —1985 $L_1$ Libration Center Mission

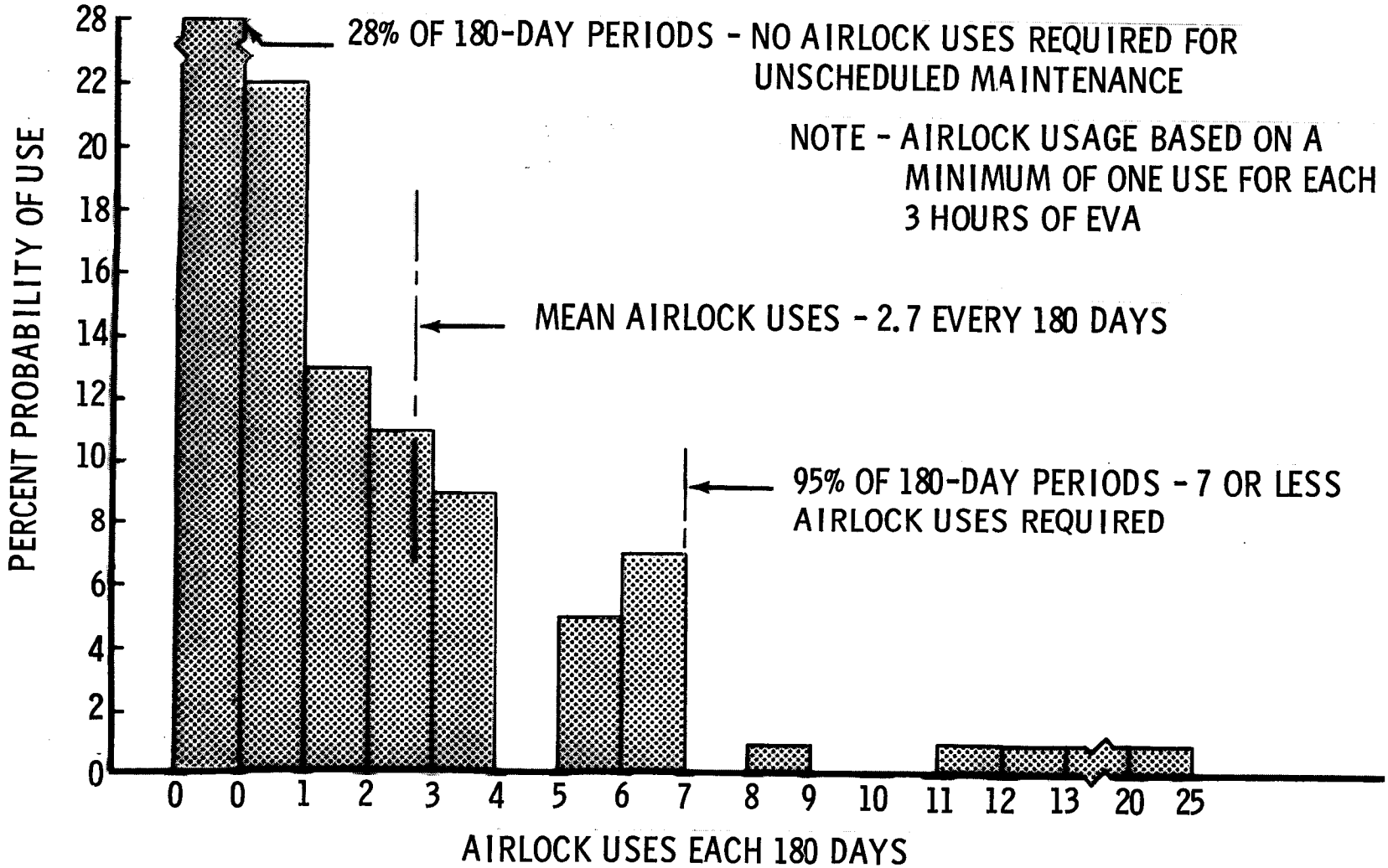


Figure 5.3-17: UNSCHEDULED MAINTENANCE AIRLOCK USAGE DISTRIBUTION — 1985 $L_1$ Libration Center Mission

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required, the average is 4.7 airlock use every 360 days, and the maximum is still 20 to 25, but this occurred only 2% of the time.

Figure 5.3-18 shows the expected manhours of spacesuit use required for any one 180-day interval. The average spacesuit use is 12.4 manhours every 180 days, 95% of the time 40 or less manhours are required, and 1% of the time a maximum of 121 to 140 manhours of spacesuit use will be required during 180 days. The 360-day simulation runs showed an average of 18.5 manhours, the 95% point was 70 manhours or less, and the maximum was 141 to 160.

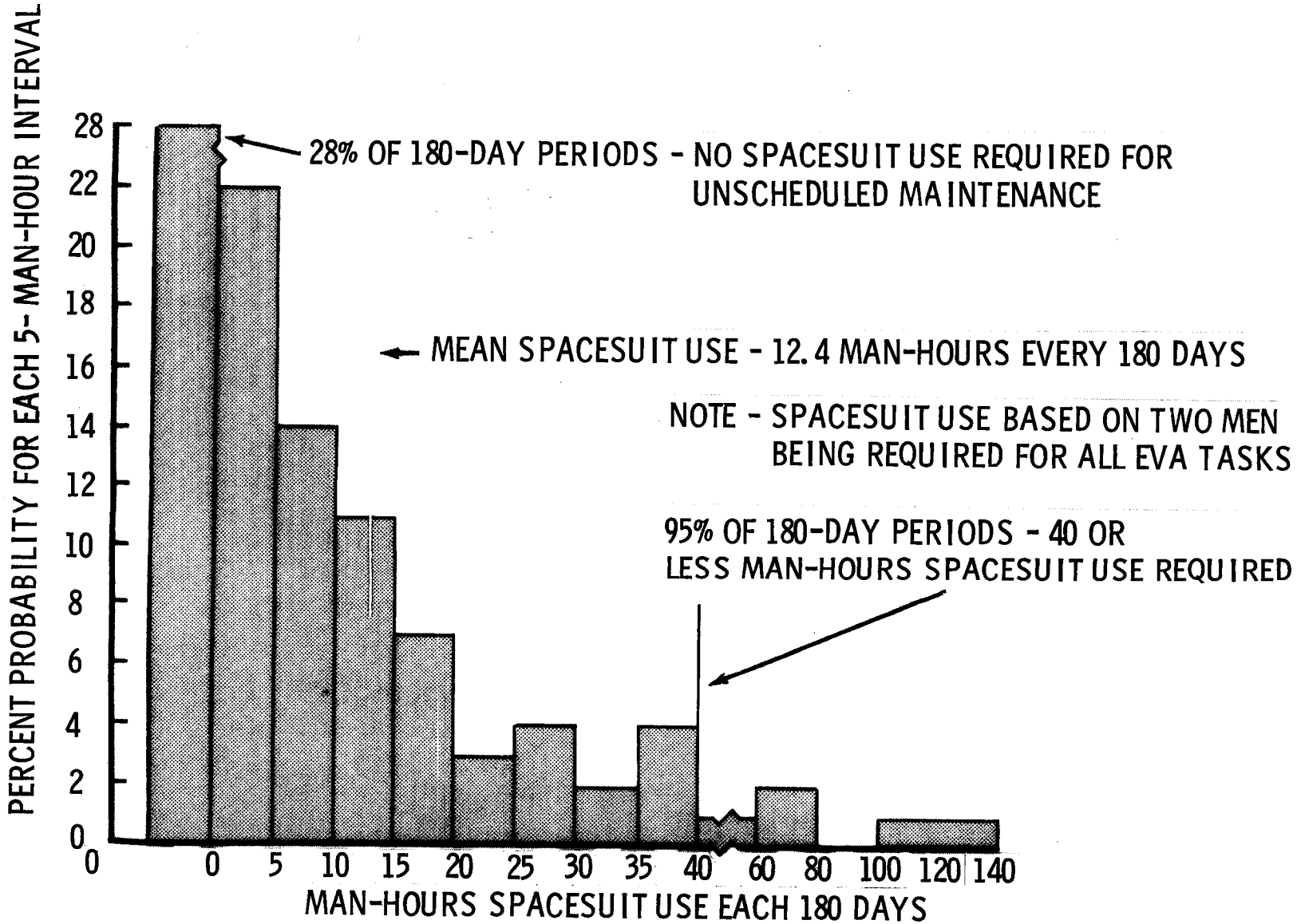


Figure 5.3-18: UNSCHEDULED MAINTENANCE SPACESUIT USAGE DISTRIBUTION — 1985 $L_1$ Libration Center Mission

# 6.0 EFFECTS OF MISSION PARAMETERS AND MAINTENANCE ON REPRESENTATIVE INTERPLANETARY MISSIONS

A number of different missions, as described in other existing studies, were evaluated for mission concepts, goals, operational characteristics, personnel and hardware requirements, and depth of detailed information to establish representative and workable baseline missions that could be analyzed in this study. Volume III of this report presents a detailed discussion of the missions selected, spacecraft configuration analyses and selections, and the spacecraft subsystem analyses. It is necessary to review this information and examine the MARCEP data sheets and maintenance task analysis sheets (also contained in Volume III) to appreciate fully the depth of data that was used as a background for the study analyses.

The effect of varying major mission/system parameters was investigated at the system level. These parameters included mission duration, weight, volume, mean repair time, and required level of repair confidence. In evaluating the effects of the mean repair time, gross errors in the estimation of repair times were assumed and applied as factors to the baseline repair times. The results of investigating the system-level effects of parametric variations are presented in Section 6.1 for the interplanetary class of missions.

Scheduled maintenance activity will have an effect on mission requirements. In particular, scheduled maintenance will affect crew workload and the weight of expendables required to conduct the mission. These aspects of scheduled maintenance are discussed in Section 6.2.

The effects of unscheduled maintenance on overall mission requirements were evaluated by conducting a series of simulations where the mission was examined under simulated real-time conditions. In the simulations, failures were allowed to occur randomly and statistics on queuing, resource expenditures, and maintenance time (which was also determined randomly) were recorded. The results of these investigations are presented in Section 6.3.

As a result of evaluating the effects of various parameters on the mission requirements, it was possible to make a preliminary estimate of the spacecraft weight and the launch payload requirements for each mission. Table 6.0-1 presents a mission weight summary for the 1975 Mars/Venus flyby mission. Table 6.0-2 presents a mission weight summary for the 1985 Mars landing mission. These mission and launch requirements are discussed in more detail in Volume III.

## 6.1 EFFECTS OF VARYING SELECTED MISSION/SYSTEM PARAMETERS

### 6.1.1 1975 MARS/VENUS FLYBY MISSION

The interplanetary spacecraft was analyzed for all the parametric variations considered for the 1975 near-Earth orbital vehicle, discussed in Section 5.1.1.

Table 6.0-1: 1975 MARS/VENUS FLYBY MISSION WEIGHT SUMMARY

| | Kilograms |
|---|---|
| **SPACECRAFT WEIGHTS** | |
| Mission Module, Earth Entry Module, Service Module, Basic nonredundant weight | 28,256 |
| Experiments: fueled probes; Mars 7951 kg (17,508 lb); Venus 4960 kg (10,922 lb) | 17,568 |
| Expendables; including cryogenic $O_2$ and $N_2$ tanks, food, water, filters, wicks, etc. | 7,440 |
| Spares and redundancies for 0.99 probability of success | 4,134 |
| Crew at 86 kg each | 516 |
| Total Unfueled Spacecraft Weight | 57,914 |
| Midcourse Correction Fuel ($I_{sp}$ = 305; V = 762 m/sec) | 26,063 |
| Total Fueled Spacecraft Weight | 83,977 |
| Weight at End of Mission (S/C less probes and midcourse fuel) | 45,003 |
| **EARTH-ORBITAL WEIGHTS** | |
| Spacecraft | 83,977 |
| Mars Vector Stage (Kick Stage) | 174,977 |
| dry weight 12,258 (26,992); fuels 162,719 (358,307); $I_{sp}$ = 305, V = 3680 m/sec | |
| Injection Stage | 575,277 |
| dry weight 43,130 (94,972); fuels 532,097 (1,171,678); $I_{sp}$ = 410, V = 4100 m/sec | |
| Total Orbital Mass | 834,181 |

Table 6.0-2: 1985 MARS LANDING MISSION WEIGHT SUMMARY

| Spacecraft Weights | Kilograms |
|---|---|
| Mission Module, Mars Excursion Module, Earth Entry Vehicle, Service Module, Basic nonredundant weight | 69,197 |
| Experiments | 3,190 |
| Expendables | 8,200 |
| Spares and Redundancies for 0.99 $P_{MS}$ | 3,528 |
| Crew at 86 kg each | 688 |
| Total Unfueled Spacecraft Weight | 84,803 |

Figure 6.1-1 shows the optimal weight growth of the spacecraft from a single-thread system to a system enhanced by redundancies and spares. The added weight is plotted against mission probabilities (crew survival and success) for various mission durations. The probability scale is an inverted log scale wherein 1.0 is at infinity, which was chosen because it allows greater plotting accuracy and visibility in the prime area of interest, that is, the higher probabilities. It is interesting to note that the growth curves closely approximate straight lines. Consistent irregularities in the family of curves, where the curve slopes change slightly, are due to transient stagnation of the optimization process caused by a heavy item (or items) that suppresses the reliability growth when the optimal selection of that component is delayed because of its weight. The component that caused the irregularity at approximately 80% probability on the crew survival curves was the Brayton cycle power conversion unit (PCS) in the electrical power subsystem. It is expected that if all components identified for optimization were of equivalent weight, the curve plotted would be indistinguishable from a straight line. This leads one to believe that the optimal selection sequence* for a given system of components will be cyclical, with a repetitive subsequence. This, of course, assumes that the ultimate probability is not limited by components with fixed probability values. If the optimal selection sequence is cyclical, once the average slope of the curve is determined the curve can be linearly extrapolated to determine the weight that must be added to achieve any desired probability. The mission success curves of Figure 6.1-1 seem to belie this statement. This is because the mission success probabilities are limited by certain components in the crew system that have fixed reliabilities less than 1.0, causing the curves ultimately to become asymptotic to the lowest fixed value.

Figure 6.1-2 presents by subsystem the end result of the optimization of the 550-day baseline mission to a 0.99 probability of mission success. Initial, or nonredundant, subsystem weights are shown by the solid bars and the weight of spares and selected redundancies added is shown by the cross-hatched bars. It is interesting to compare the data management weights for this mission with the data management weights shown for the 1975 near-Earth orbital mission in Figure 5.1-6. The initial weight of the interplanetary spacecraft data management subsystem is higher than that for the orbital vehicle because of some additional items considered as part of the subsystem. In spite of this, the added weight for the interplanetary subsystem is lower than that for the orbital subsystem. This is because of a basic difference in the maintenance philosophy for the two subsystems. The orbital subsystem is structured so that the on-board computer and the data adapter are replaceable as complete units only. This accounts for the large amount of added weight, because these items are the most massive items in the subsystem and they are spared as complete units. In the interplanetary mission a different approach was taken. The computer and data adapter were arbitrarily modularized into replaceable subunits. This resulted in a remarkable reduction in the weight of spares added to support the mission. The greatest disparity between initial weight and

* This is an optimal process <u>only</u> within the boundaries of the component system described.

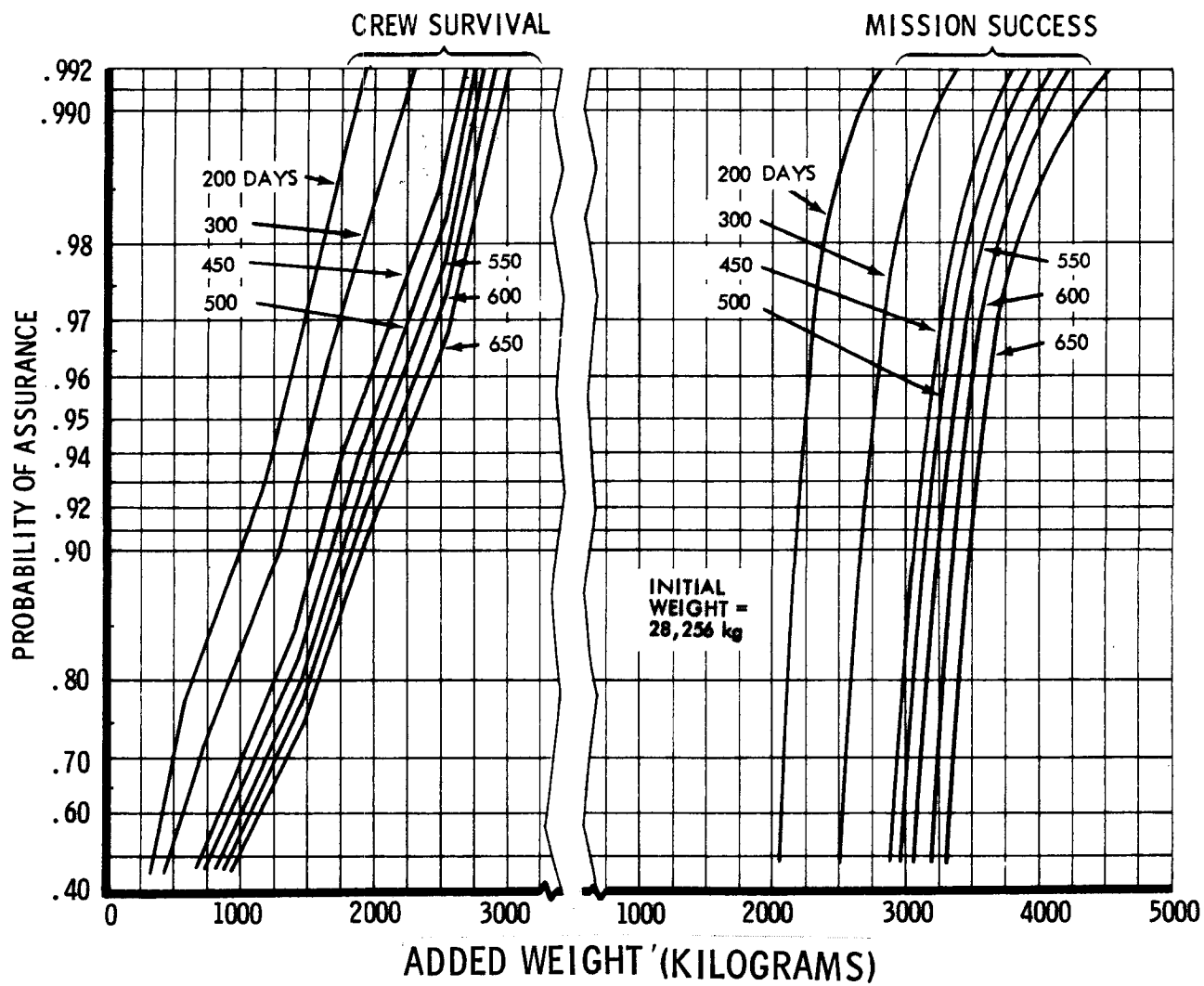


Figure 6.1-1 ADDITIONAL WEIGHT REQUIRED TO ACHIEVE PROBABILITY OF ASSURANCE — 1975 Mars/Venus Flyby Mission

Figure 6.1-2: SUBSYSTEM INCREMENTAL WEIGHTS — 1975 Mars/Venus Flyby Mission

added weight occurred in the experiment, reentry, extravehicular activity, and structure subsystems. This is because these subsystems were supported almost entirely by repair kits. Repair kits were planned because it was considered unrealistic to spare or make redundant major elements of the spacecraft structure, or similar items from the experiment, reentry, and extravehicular activity subsystems. The communications subsystem was the only subsystem that required more than the basic weight to be added to achieve the 0.99 mission success probablity. This was in part due to the high failure rate and the weight of the 500-watt transmitter. Six spare transmitters were added for a total weight penalty of 54 kilograms.

Figure 6.1-3 investigates the sensitivity of mission duration, and added weight of spares and selected redundancies, to gross errors in the estimated repair task times. It can be seen that a 50% underestimation of all repair task times (MTTR = 1.5) results in only a 200-kilogram increase in added weight for a 550-day mission. The added weight results from addition of components in parallel and standby redundancy rather than as spares when the desired confidence of repair cannot be attained within the maximum allowable downtime. The confidence requirements for this sensitivity investigation were 0.99 for repair of safety critical components and 0.95 for all other components. Repair confidence levels and their application in this study are discussed in Section 3.3 of this document.

In a similar manner, Figures 6.1-4 and 6.1-5 show the sensitivity of added weight (and volume) and mission duration to variations in the required repair confidence levels. The confidence levels investigated were: 0.9999/0.999; 0.999/0.99; 0.99/0.95; 0.95/0.90; 0.90/0.80; and 0.80/0.70 for safety critical/other components, respectively. There was no distinguishable difference between the added weights for confidences 0.99/0.95 and 0.95/0.90, and 0.90/0.80 and less. This is because of the combination of components, their repair task times, and the maximum allowable downtimes specified for this mission. The added weight for a specific mission is not as sensitive to repair confidence as was originally anticipated. The penalty caused by increasing the repair confidences from 0.99/0.95 to 0.9999/0.999 was only 340 kilograms. Conversely, the reduction of repair confidence below 0.99/0.95 resulted in relatively minor gains. This seemed to indicate that a repair confidence of 0.99/0.95 is practical to specify for design of repairable spacecraft items. The incremental weights gained or lost in changing from one confidence level to another are independent of mission duration, as indicated by the curves. This also substantiates the use of 0.99/0.95 repair confidences as a best choice for specifications, even though the percentage gain through the use of a lower confidence at shorter mission times is greater. The above discussion applies similarly to the volume curves shown in Figure 6.1-5.

Figure 6.1-6 was derived for one mission only; the 1975 interplanetary mission. This figure provides a means of estimating the additional weight that must be added to a mission vehicle to achieve a desired probability of crew survival for a given mission duration. This figure applies only to a flyby mission module, the midcourse propulsion package, and the Earth reentry vehicle. The percentage found from the curves is the percentage weight that

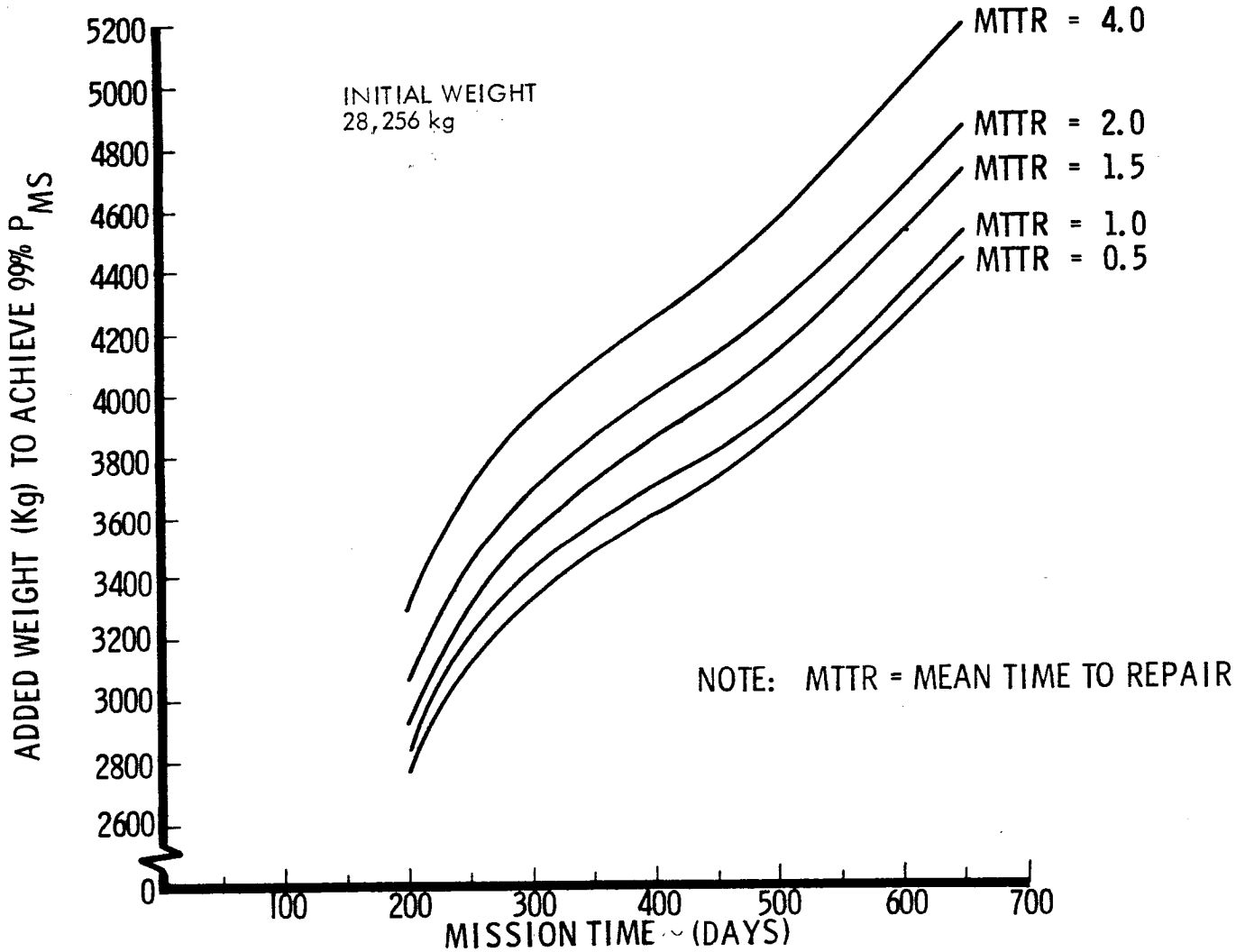


Figure 6.1-3: MISSION TIME VS ADDED WEIGHT FOR MTTR VARIATIONS —1975 Mars / Venus Flyby Mission

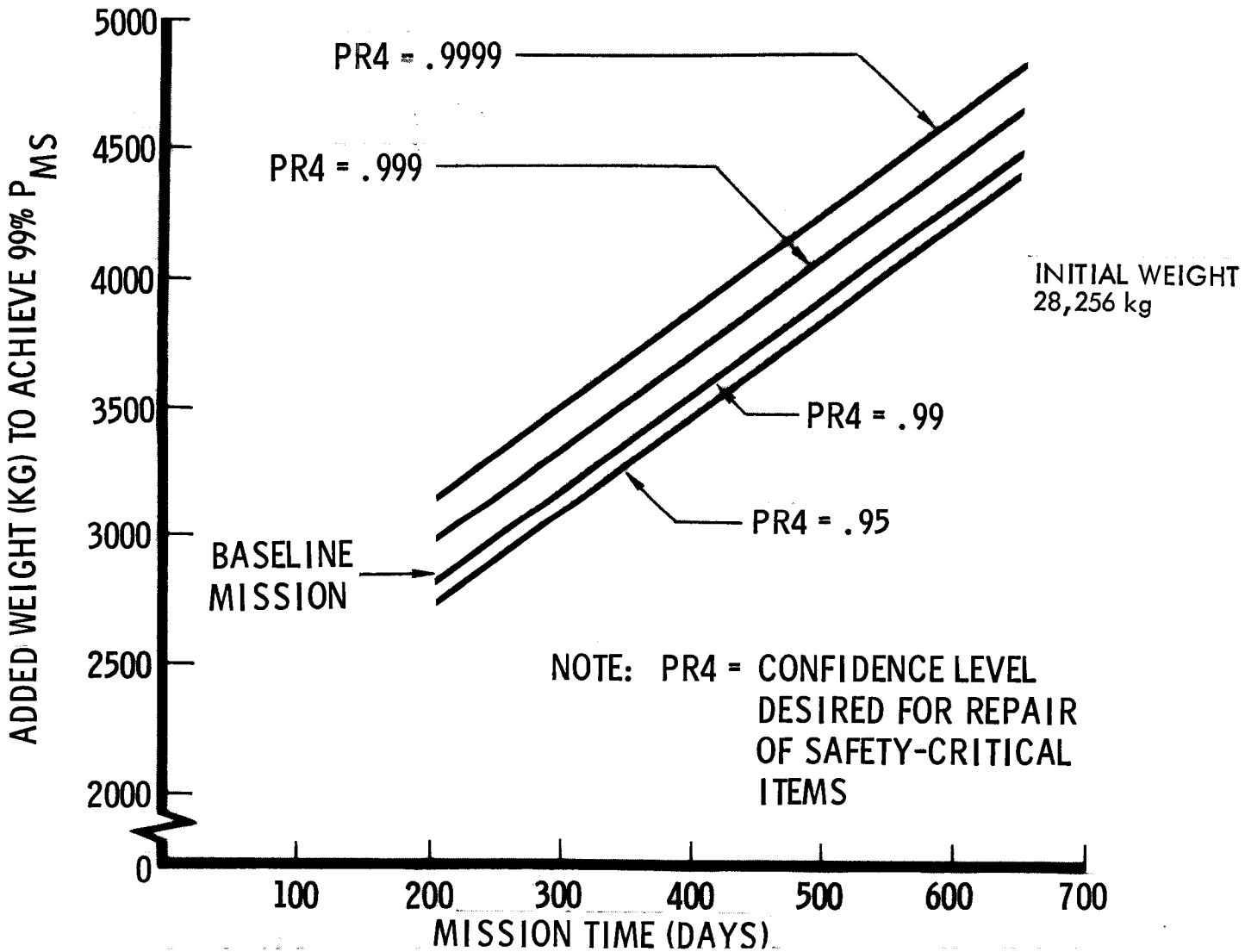


Figure 6.1-4: MISSION TIME VS ADDED WEIGHT FOR CONFIDENCE LEVEL VARIATIONS — 1975 Mars/Venus Flyby Mission

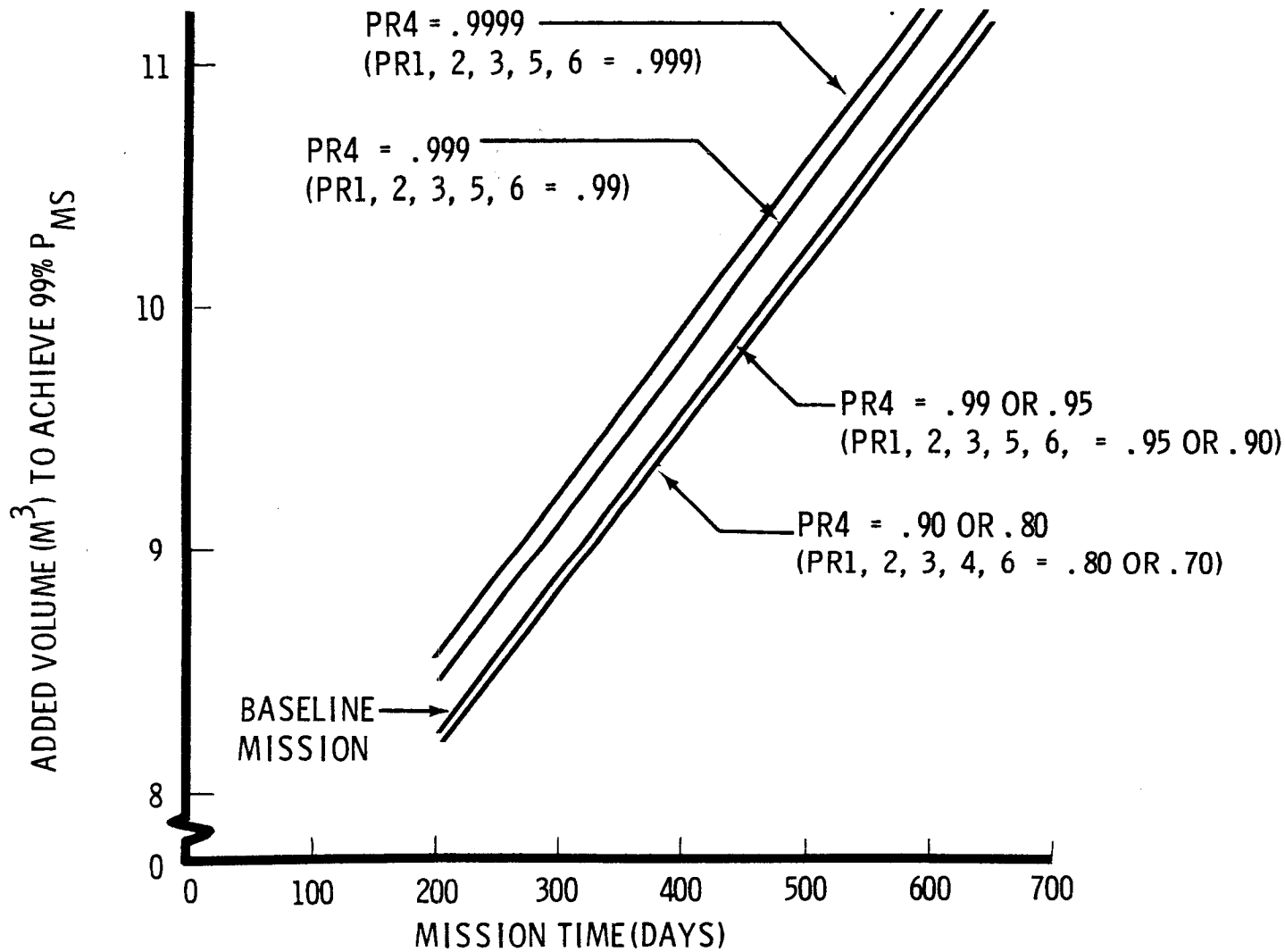


Figure 6.1-5: MISSION TIME VS ADDED VOLUME FOR CONFIDENCE LEVEL VARIATIONS — 1975 Mars/Venus Flyby Mission

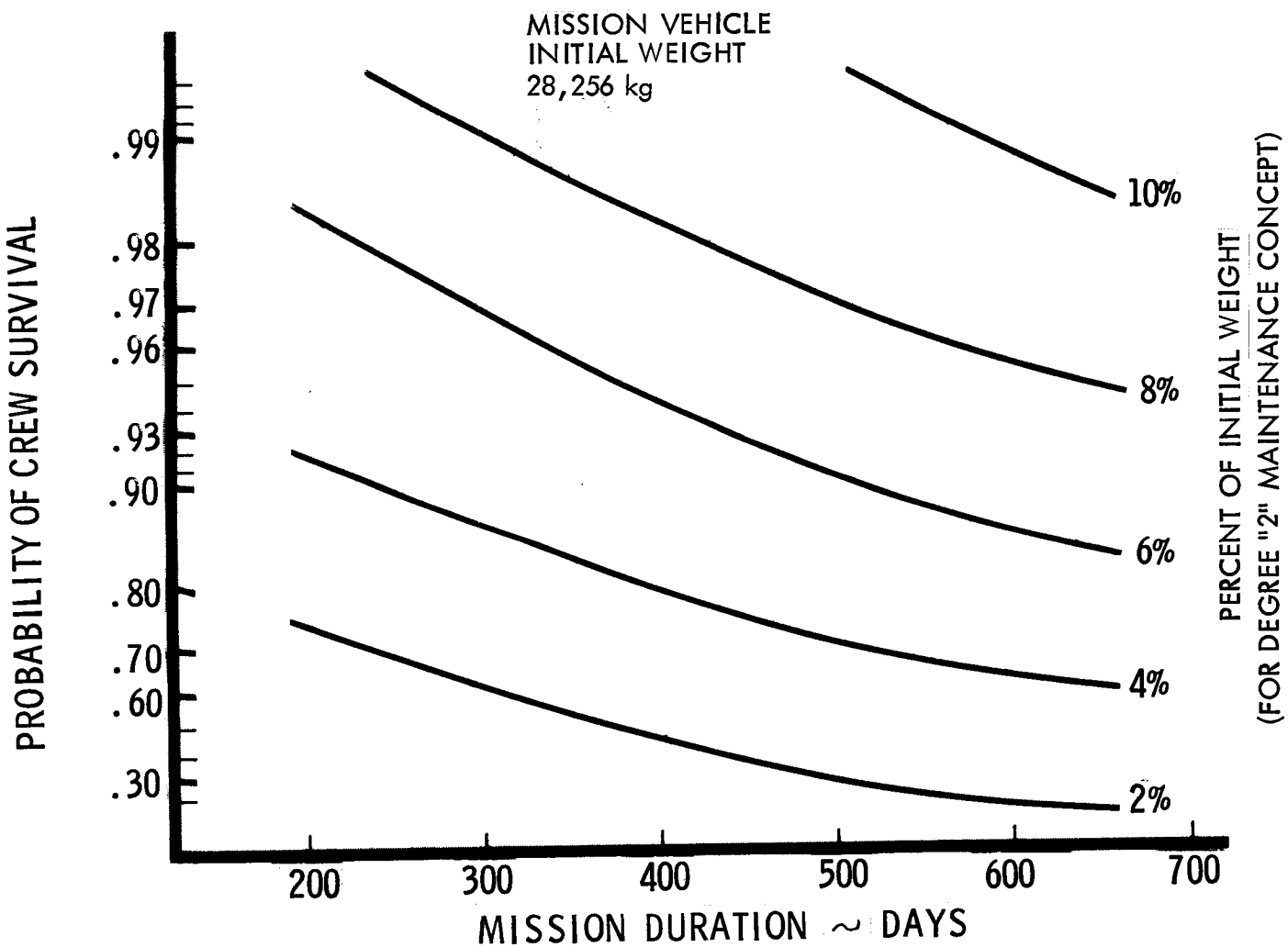


Figure 6.1-6: MISSION TIME VS PROBABILITY OF CREW SURVIVAL FOR PERCENTAGE OF SPARES AND REDUNDANCY —1975 Mars/Venus Flyby Mission

must be added to the basic (nonredundant and dry) weight of the mission module, midcourse propulsion package, and Earth reentry vehicle. The figure should be used for planning and sizing purposes only, and in these uses should give reasonably good results, assuming the maintenance concept for the manned vehicle is not widely divergent from that specified for the 1975 interplanetary mission of this study.

### 6.1.2 1985 MARS LANDING MISSION

Figure 6.1-7 is a 1985 version of Figure 6.1-1. The four mission time variations were selected because they are for specific Mars-capture trajectories with a 30-day Mars stay-time. It can be seen that slightly less additional weight is required to achieve the prerequisite 99% probability of crew survival than was required for the 1975 interplanetary mission. Improvements in component weights, failure rates, and more modularization for maintenance were assumed for 1985. One specific application of modularization was to the on-board computer. The effects of this are discussed in more detail with Figure 6.1-12. The improvements established have more than balanced the larger crew size (8), which accounts for the decrease in added weight. The weights added to improve probability of mission success are significantly lower for 1985. This is because the on-board experiment subsystem is smaller. No probes were identified for this mission because of the planetary lander (MEM). This explains the low amount of weight added to improve mission success. Generally, it was found that the curves of Figure 6.1-7 are not far different from the 1975 interplanetary mission analysis curves of Figure 6.1-1. The characteristics of these curves are described in more detail in Section 6.1.1.

It should be noted here that the MEM was not considered in the curves of Figure 6.1-7. The MEM mission is classified as a sub-mission whose probabilities must be considered apart from the parent mission. The probability of crew survival for the MEM sub-mission was assumed to be 99% according to the following conditions. The MEM will be checked out in detail before launch. It is assumed that the final check will ensure descent and ascent engine operation. The probability of other MEM subsystems operation during the sub-mission is assured by adding, by weight only, packages of redundancy and spares to the subsystems. The weight of the packages was estimated on a percentage basis from the analysis of the 1975 30-day Earth-orbital mission (30-day resupply period). Table 6.1-8 indicates the weights of the redundancy and spares packages estimated for the MEM.

Figure 6.1-9 presents by subsystem the end results of the optimization of the baseline 460-day mission. Comparison of this figure with Figure 6.1-2 shows the differences between the 1975 and 1985 interplanetary missions. The electrical power subsystem initial weight is about 1000 kilograms heavier than for the 1975 mission. This is due to the increased shield weight and component weights required for the higher power levels of the mission. Included in the basic weight is a single Brayton cycle power conversion assembly. Two are required for the mission, but only one is required for crew survival. The weight of the second unit is included in the weight added. This unit was added in parallel redundancy and will be operated at rated power for all

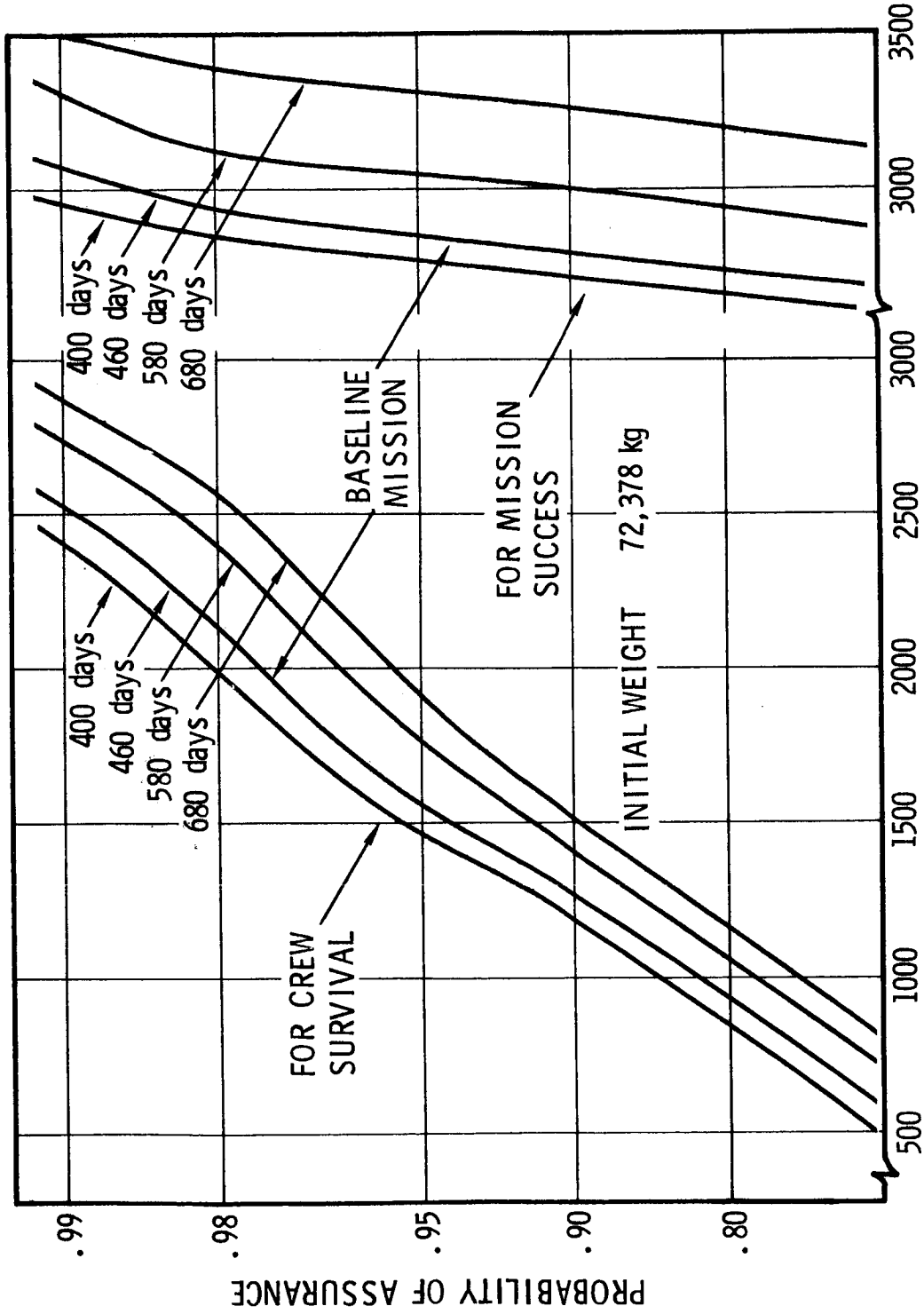


Figure 6.1-7: ADDITIONAL WEIGHT REQUIRED TO ACHIEVE PROBABILITY OF ASSURANCE — 1985 Mars Landing Mission

Table 6.1-8: MEM ALLOCATED WEIGHTS

| Mars Planetary Lander Subsystems | Kilograms |
|---|---|
| | Allocated Redundancy & Spares |
| PL 541 Electrical Power | 46.65 |
| PL 542 Electronics | 22.2 |
| PL 543 Instrumentation | 31.95 |
| PL 544 Reaction Control | 37.50 |
| PL 545 Stability Control | 3.08 |
| PL 546 Life Support & Crew System | 114.75 |
| PL 547 Communications | 10.88 |
| PL 548 Propulsion | 123.30 |
| PL 549 Navigation and Guidance | 11.93 |
| PL 550 Controls and Displays | 6.80 |
| | 409.04 |
| | Basic Descent Stage Weights |
| Structure | 2479.0 |
| Electrical Power | 395.0 |
| Electronics | 296.0 |
| Instrumentation | 340.0 |
| Reaction Control | 268.0 |
| Life Support & Crew Systems | 985.0 |
| Landing Gear | 926.0 |
| Parachutes | 3555.0 |
| Payload | 363.0 |
| RCS Propellant | 404.0 |
| Descent Propellant | 6016.0 |
| | 16027.0 |
| | Basic Ascent Stage Weights |
| Structure | 1135.0 |
| Electrical Power | 227.0 |
| Stability Control | 41.0 |
| Instrumentation | 86.0 |
| Reaction Control | 232.0 |
| Life Support & Crew Systems | 545.0 |
| Communications | 145.0 |
| Propulsion System (Common) | 1644.0 |
| Payload | 404.0 |
| RCS Propellant | 313.0 |
| Ascent Propellant | 2508.0 |
| Navigation and Guidance | 159.0 |
| Controls and Displays | 91.0 |
| | 17530.0 |
| TOTAL | 33,966.0 |

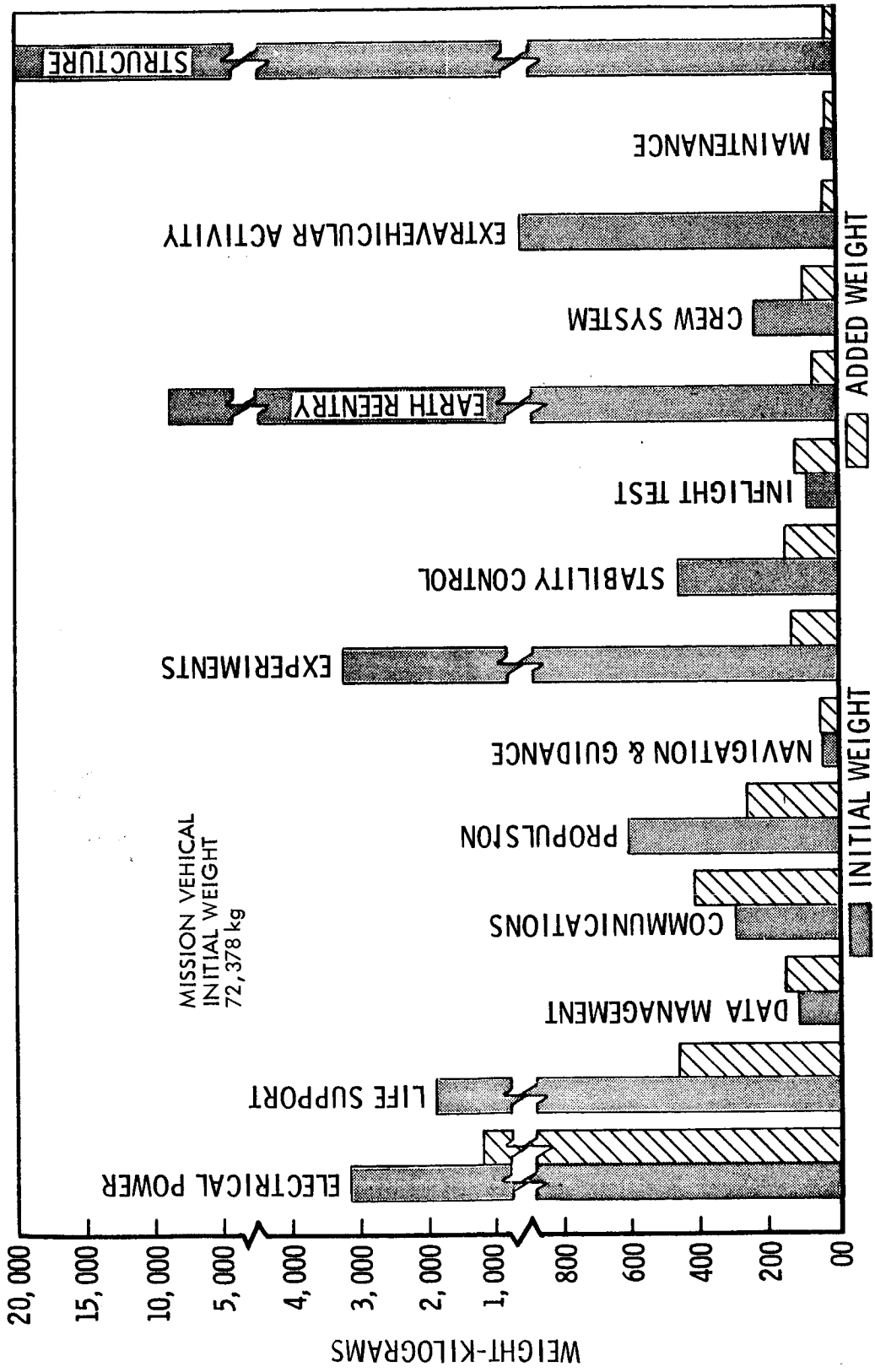


Figure 6.1-9: SUBSYSTEM INCREMENTAL WEIGHTS — 1985 Mars Landing Mission

experiment and nonessential equipment requirements. Switchover capability is assumed so the second unit can carry essential loads if the first unit fails. This concept is discussed in Section 1.4 of the Appendix, in relation to Figure I-4. In spite of the increased power requirements and higher weights for this mission, the weight added to the electrical power subsystem was approximately the same as added for the 1975 interplanetary mission.

The life support subsystem shows an increase in initial weight, and a decrease in added weight. This is due to the increased crew size and improvement in component MTBF's.

The data management subsystem shows a significant decrease in initial weight. This decrease is due to elimination of many sensors, with the remainder assumed to be integral with other subsystems, and primarily due to reallocation of the film developer rolls to the experiment subsystem. Thus, the decrease in initial weight is not due entirely to component weight improvements.

The navigation and guidance subsystem initial weight is about half that for the 1975 mission due to design improvements. The added weight is far less than that added for the 1975 mission due to decreases in component failure rates expected between 1975 and 1985.

The experiment subsystem initial weight is well below that for the 1975 Mars/Venus flyby mission because the heavy probes are not required for the Mars landing mission. The weight of repair kits added to the experiment subsystem is about half that added for the 1975 mission.

The stability and control subsystem is initially heavier because of control-moment gyros (CMG's) required to maintain orientation of the spacecraft with respect to the Sun.

The remaining spacecraft subsystems compare well with the 1975 subsystems. Differences in initial and added weights are due to the increased crew and improvements in component weights and failure rates.

Figure 6.1-10 shows the sensitivity of added weight with respect to variations in mission time and mean-time-to-repair. As explained in Section 6.1.1, increasing mean-time-to-repair (MTTR) by a factor causes an increase in weight added to get the same level of reliability. The increase in weight added is due to additions of parallel and standby redundancy caused by failure to meet required probabilities. MTTR times a factor of 4.0 was not evaluated; however, the variations evaluated are not too different from the 1975 curves of Figure 6.1-3. The delta difference between added weights for MTTR times 1.0 and MTTR times 1.5 appears to be about the same for the 1975 and 1985 time periods. The difference is approximately 100 kilograms across all the mission times.

Figures 6.1-11 and 6.1-12 investigate the sensitivity of added volume to variations in the MTTR, repair confidence, and mission time parameters. An interesting anomaly is present on both of these figures. The rapid upswing of the volume curve after 600 days mission time seems to indicate an asymptotic

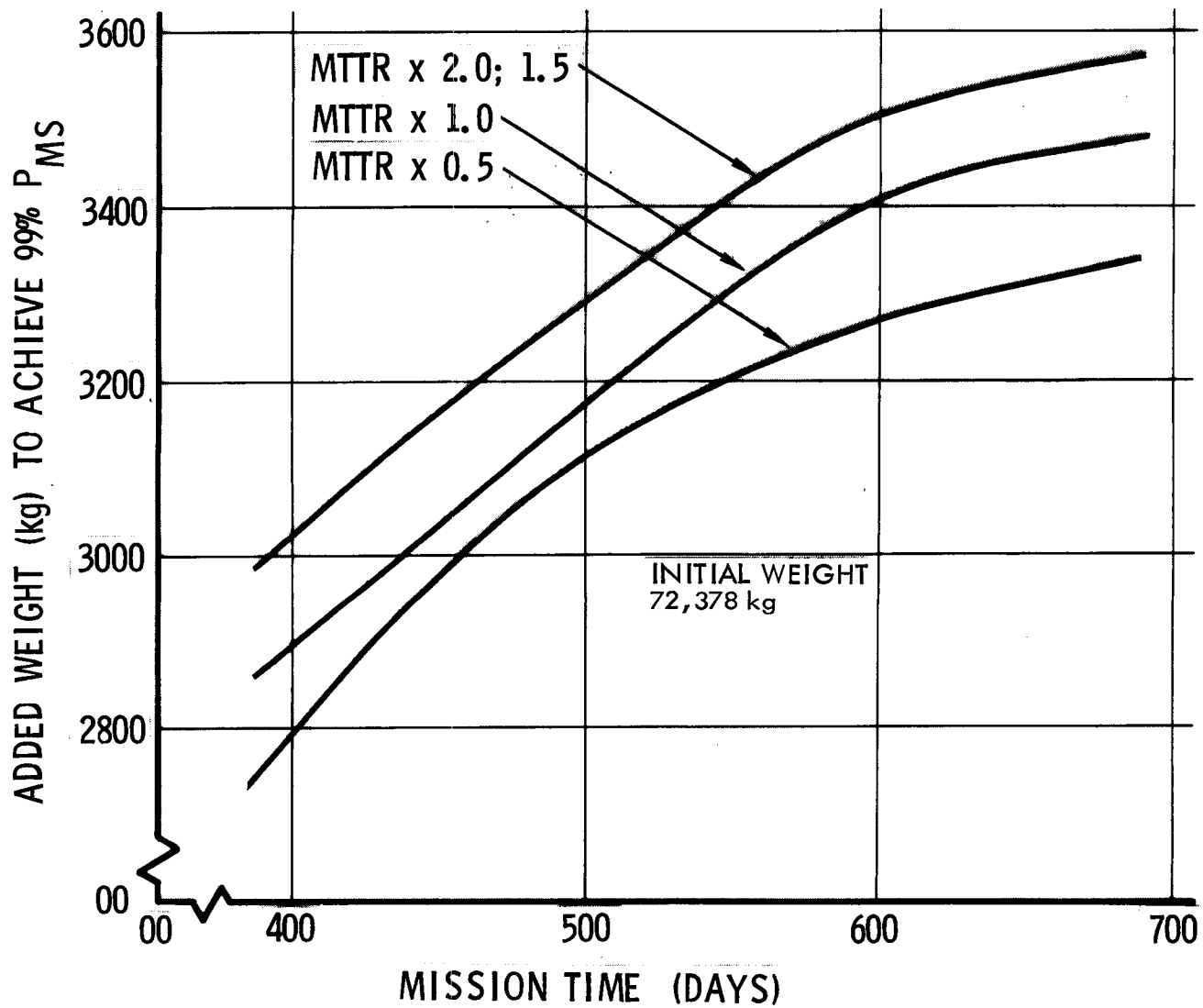


Figure 6.1-10: MISSION TIME VS ADDED WEIGHT FOR MTTR VARIATIONS — 1985 Mars Landing Mission

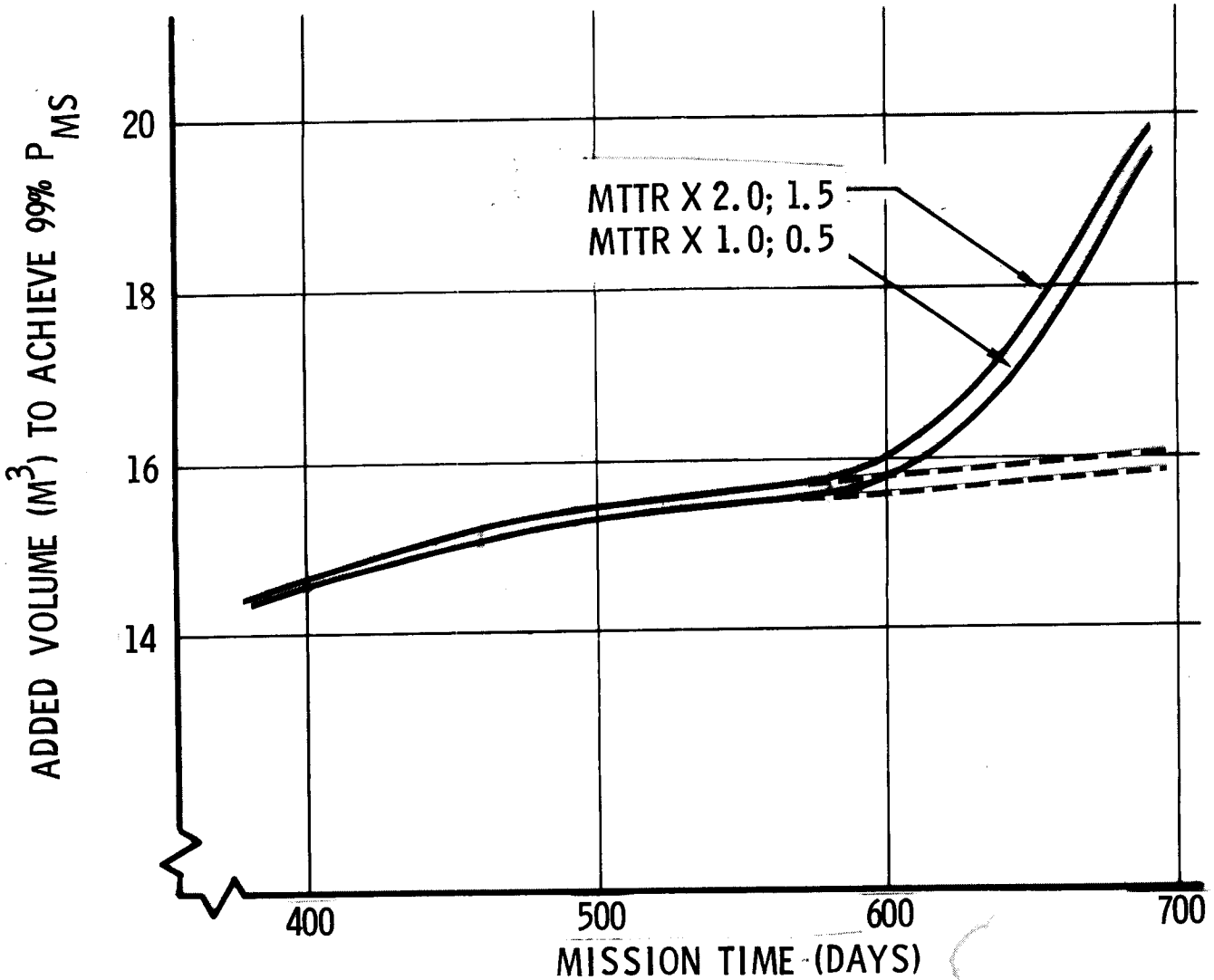


Figure 6.1-11: MISSION TIME VS ADDED VOLUME FOR MTTR VARIATIONS — 1985 Mars Landing Mission

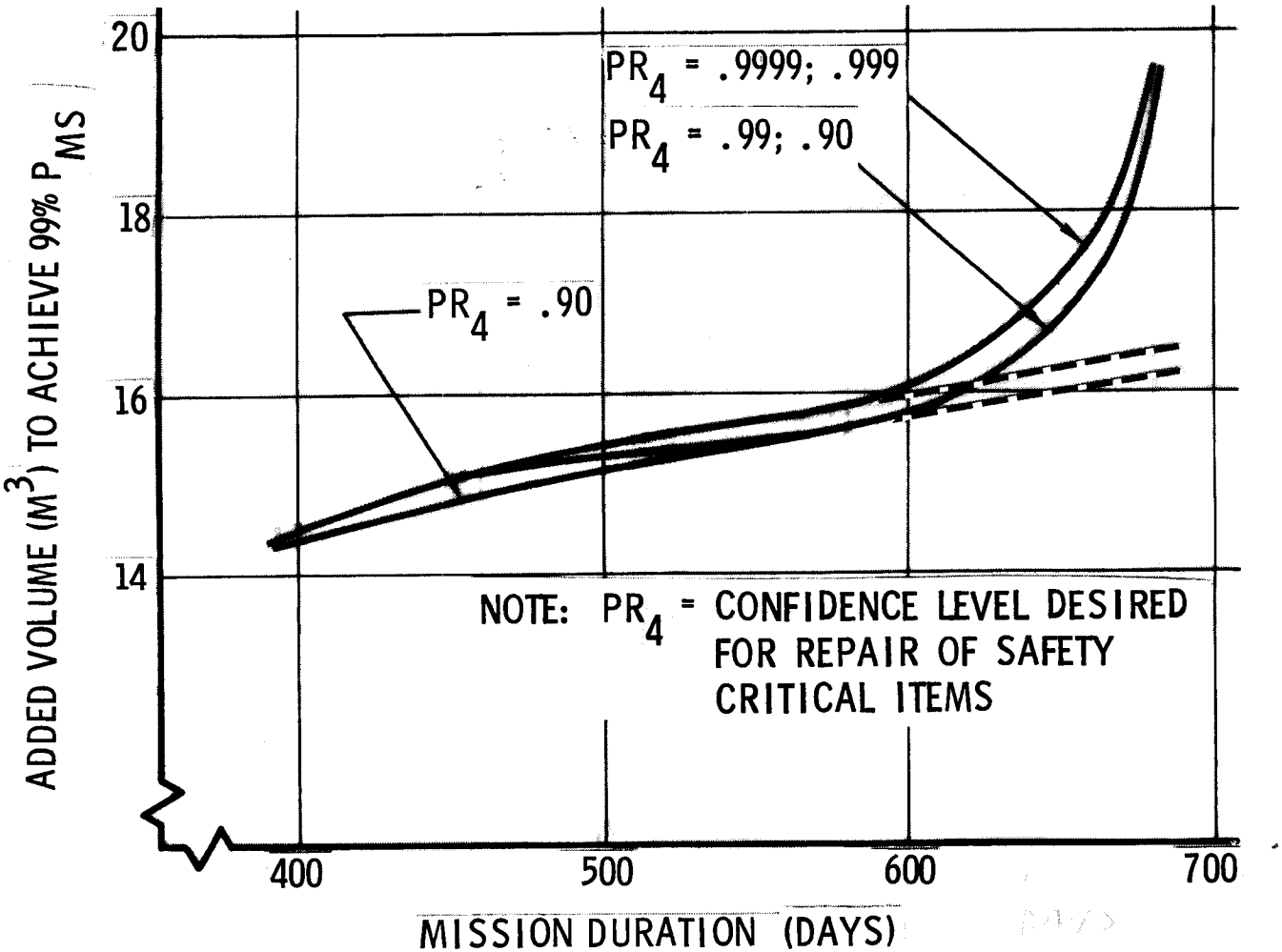


Figure 6.1-12: MISSION TIME VS ADDED VOLUME FOR CONFIDENCE LEVEL VARIATIONS — 1985 Mars Landing Mission

situation. Obviously this cannot be correct. It was found that this was caused by the last component added for the 680-day mission. The component happened to be the telescope and optical system required for the laser communications subsystem (item coded CM 183). This item is the reflecting telescope tube and mirrors, and it is relatively light compared to its volume. At 400 days, it had already been added as a spare assembly that accounts for the high added volume at 400 days in comparison to the other missions. A plateau is apparent between 400 and 600 days, where low volume items are being added. At 680 days, a second spare telescope assembly is added causing the upswing. If longer mission times were examined, a second plateau would be found, probably extending between 700 and about 1200 days.

It can be seen in Figure 6.1-12 that the upper two confidences share a common curve, and that the lower two confidence levels share a common curve beyond 550 days. Before 450 days, the 99% confidence level is coincident with the 99.99% and 99.9% confidence levels, and crosses over to meet the 90% confidence level line during the 450 to 550 day range. The broken line extensions indicate the expected volume trend if the telescope tube and mirror assembly were not spared at 680 days. In other analyses, high added weights have led to modularization of assemblies and sparing of the modules. This is the first apparent instance where volume effects seem to indicate the necessity for modularization. It appears reasonable that the telescope tube could be repaired by kit rather than by replacement with a spare. The mirrors and other optics could be designed to be replaceable, and spared individually.

Figure 6.1-11 shows the same characteristics noted for the curves of Figure 6.1-12. It is interesting to note the similarity in the curve characteristics and spacing on the two previous figures. This indicates the interrelationship of repair confidence level and component mean-time-to-repair. The broken line extensions again indicate the expected volume trend if the telescope tube assembly were not added at 680 days.

Weight sensitivity to mission time and changes in the required levels of repair confidence are shown on Figure 6.1-13. The confidence levels investigated are the same as for the 1975 missions except that some of the lower levels were eliminated. Confidence levels for the repair of safety critical components of 0.9999, 0.999, 0.99, and 0.90 were investigated. Confidence levels for nonsafety critical components were assumed as 0.999, 0.99, 0.95, and 0.80, respectively. Investigation of the upper two confidences resulted in essentially the same curve, as indicated in the figure. The curves did show a definite curvature that was not apparent in the curves for the 1975 mission, (Figure 6.1-4). The scaling of the 1975 curves may have prevented determination of the curvature. The curvature for the 1985 mission seems to approach a limiting value. Logically, this cannot be the case until a completely time independent, self-sustaining entity is produced. It is assumed that a temporary plateau or transition is being approached, and if longer mission times were analyzed, an upward trend would again be observed. The upper two confidence curves are separated from the 0.99 (baseline) confidence curve by about 100 kilograms, which is about the same as the difference between the baseline, 0.99, curve and the 0.999 curve for the 1975 mission. The whole spectrum of repair

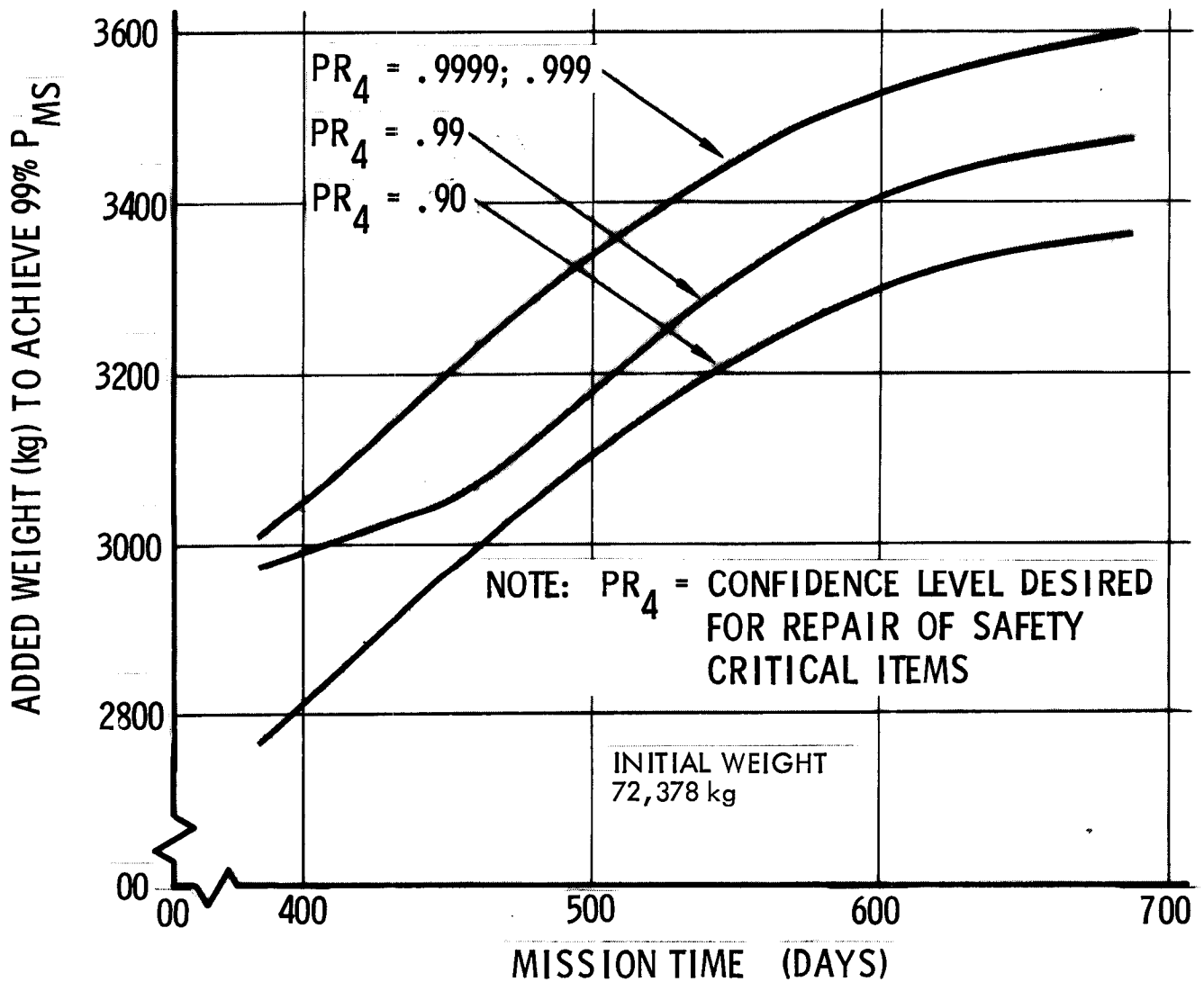


Figure 6.1-13: MISSION TIME VS ADDED WEIGHT FOR CONFIDENCE LEVEL VARIATIONS — 1985 Mars Landing Mission

confidence curves leads one to the conclusion that the weight to be added to the spacecraft is relatively insensitive to the repair confidence level, at least up to a confidence of 0.9999. The overall change of about 200 kilograms from 0.90 to 0.9999 confidence represents only 5.5% of the total weight added for mission success.

## 6.2 EFFECTS OF SCHEDULED MAINTENANCE ON OVERALL MISSION REQUIREMENTS

Scheduled maintenance, which by definition occurs at preplanned times instead of randomly, could be determined directly from the maintenance task analysis sheets included in Volume III. The following sections summarize the scheduled maintenance requirements by subsystem, skill, maintenance interval, and expendables weight allocation for the 1975 and 1985 planetary class missions.

### 6.2.1 1975 MARS/VENUS FLYBY MISSION

Table 6.2-1 summarizes the scheduled maintenance requirements for this mission within each frequency interval, by minutes required for each skill level to perform the task. Where more than one task of a given type is indicated by parentheses, the time shown is the total required. Also indicated on this table is the subsystem code number of the item being serviced and the service time by skill required to perform scheduled servicing. The code number refers to the identification used in the MARCEP data sheets included in Volume III. Resources required to perform the scheduled maintenance are indicated in Table 6.2-1 by the resource identification numbers, which are given in Table 6.2-2. The resources most frequently used are the standard maintenance tool kit and the vacuum system identified by Codes 1 and 2, respectively. Lamps for various types of lighting equipment are shown as scheduled replacement items, whereas they actually will not be replaced until they burn out. The replacement schedule is based on the average expected lamp wearout life.

Table 6.2-3 summarizes the total man-minutes and average man-minutes per day for the scheduled maintenance required at 1- , 3- , 7- , 21- , 30- , and 90-day intervals for each subsystem. It is expected that these tasks could be apportioned over all the days throughout the 550-day mission so that the time expended per day could be evened out and a relatively constant scheduled maintenance load can be realized.

Table 6.2-4 summarizes required scheduled maintenance by skill and maintenance interval, indicating the total man-minutes required. These two tables do not indicate scheduled maintenance requirements beyond 90 days; it is felt that the maintenance actions occurring beyond 90 days are of an overhaul nature and cannot be averaged out over the entire mission. Special mission planning must be accomplished to accommodate scheduled maintenance actions occurring at intervals greater than 90 days.

Detailed expendables requirements for a six-man flyby mission are listed on data sheets in Volume III. Figure 6.2-5 summarizes these by subsystem, as a function of mission duration.

Table 6.2-1: SCHEDULED MAINTENANCE - 1975 MARS/VENUS FLYBY MISSION

| Code | Item | Task | Time/skill (min.) LS | EE | GC | ME | ST | CM Resources |
|---|---|---|---|---|---|---|---|---|
| | | DAILY | | | | | | |
| IF | Console Displays | Check & record readings | | 10 | | | | |
| LS | Life Support System | Gross general inspection | 10 | | | | | |
| | | 3 DAYS | | | | | | |
| LS | Carbon Collection Bag | Replace bag | 15 | | | | | 1,2 |
| | | 7 DAYS | | | | | | |
| CS | Spacecraft Interior | General cleaning | 180 | | | 180 | | |
| LS | Urine Filter | Replace filter (1) | 30 | | | | | |
| LS | Life Support System | General Inspection | 30 | | | | | |
| | | 21 DAYS | | | | | | |
| LS | Evaporation Wick | Replace wick (1) | 30 | | | | | |
| | | 30 DAYS | | | | | | |
| LS | Charcoal Filter, Gas | Replace filter (2) | 30 | | | | | 1,2 |
| LS | Charcoal Filter, Fluid | Replace filter (2) | 40 | | | | | 1,2 |
| LS | Charcoal & Particulate Filter | Replace filter (2) | 30 | | | | | 1,2 |
| LS | Absolute Filter | Replace filter (1) | 15 | | | | | 1,2 |
| LS | Catalytic Cartridge | Replace (2) | 40 | | | | | 1,2 |
| LS | Gas Chromatograph | Calibrate | | 60 | | | | |
| LS | Mass Spectrometer | Calibrate | | 60 | | | | |
| LS | Life Support System | Check instrumentation, operate manual valves | 60 | | | | | |
| CS | Vacuum Cleaner | Change bag | | | | 10 | | |
| CS | Fire Extinguishers | Inspect | | | | 30 | | |

Table 6.2-2: MAINTENANCE RESOURCE CODE IDENTIFICATION
1975 MARS/VENUS FLYBY MISSION

| Maintenance Resource | Code Number |
|---|---|
| Standard Tool Kit | 1 |
| Vacuum System | 2 |
| Space Power Tool Kit | 3 |
| Electron-Beam Welder | 4 |
| Stemfab Tool | 5 |
| Leak Detection Equipment | 6 |
| Temperature Measuring Device | 7 |
| Pressure Measuring Device | 8 |
| Water Test Kit | 9 |
| Battery Test Kit | 10 |
| Electrical Repair Kit | 11 |
| Lubrication Kit | 12 |
| Fabric Repair Kit | 13 |
| Airflow Meter | 14 |
| Life Saving Bag | 15 |
| Aux. Life Support System | 16 |
| Special Attachment and Towing Devices | 17 |
| MMU | 18 |
| RMU | 19 |
| AEV | 20 |
| Locomotion and Restraint | 21 |
| Insulation Repair Kit | 22 |
| Spare Fitting Kit | 23 |
| Spacesuit Repair Kit | 24 |
| Life Support System Repair Skill | 51 |
| Electrical/Electronic Repair Skill | 52 |
| Mechanical Repair Skill | 53 |
| Structural Repair Skill | 54 |
| Communications Repair Skill | 55 |
| Guidance and Control Repair Skill | 56 |
| Medical Skill | 57 |
| Scientist-Experiment Skill | 58 |

Table 6.2-3: SUBSYSTEM SCHEDULED MAINTENANCE REQUIREMENTS - 1975 MARS/VENUS FLYBY MISSION

| Subsystem | Man-Minutes/Maintenance Interval (days) 1 | 3 | 7 | 21 | 30 | 90 | Average Man-Minutes/Day |
|---|---|---|---|---|---|---|---|
| Crew System | | | 360 | | 40 | 40 | 53.2 |
| Data Management | | | | | | 110 | 1.2 |
| Electrical Power | | | | | 300 | | 10.0 |
| Extravehicular | | | | | | 30 | 0.3 |
| Experiments | | | | | | 30 | 0.3 |
| Inflight Test | 10 | | | | 30 | | 11.0 |
| Life Support | 10 | 15 | 60 | 30 | 335 | 260 | 39.1 |
| Propulsion | | | | | 480 | | 16.0 |
| Reentry System | | | | | | 360 | 4.0 |
| Structure | | | | | 360 | | 12.0 |
| Total Man-Minutes | 20 | 15 | 420 | 30 | 1545 | 830 | |
| Average Man-Minutes/Day | 20 | 5 | 60 | 1.4 | 51.5 | 9.2 | 147.1 |

NOTE: Scheduled maintenance required at intervals greater than 90 days and at the resupply periods are not shown in the above summary as these tasks must be done at about the time indicated and cannot realistically be apportioned over a number of days.

Table 6.2-4: SCHEDULED MAINTENANCE CREW SKILL REQUIREMENTS - 1975 MARS/VENUS FLYBY MISSION

| Skill | Man-Minutes/Maintenance Interval (Days) 1 | 3 | 7 | 21 | 30 | 90 | Total Man-Minutes/Day |
|---|---|---|---|---|---|---|---|
| Communications | | | | | | 80 | 0.9 |
| Electrical/Electronic | 10 | | | | 300 | 390 | 24.3 |
| Guidance & Navigation | | | | | | 60 | 0.7 |
| Life Support | 10 | 15 | 240 | 30 | 215 | 240 | 60.6 |
| Mechanical | | | 180 | | 610 | 60 | 46.7 |
| Structures | | | | | 420 | | 14.0 |
| Total Man-Minutes | 20 | 15 | 420 | 30 | 1545 | 830 | |
| Average Man-Minutes/Day | 20 | 5.0 | 60.0 | 1.4 | 51.5 | 9.2 | 147.1 |

NOTE: Scheduled maintenance required at intervals greater than 90 days is not shown in the above summary as these tasks must be done at about the time indicated and cannot realistically be apportioned over a number of days.

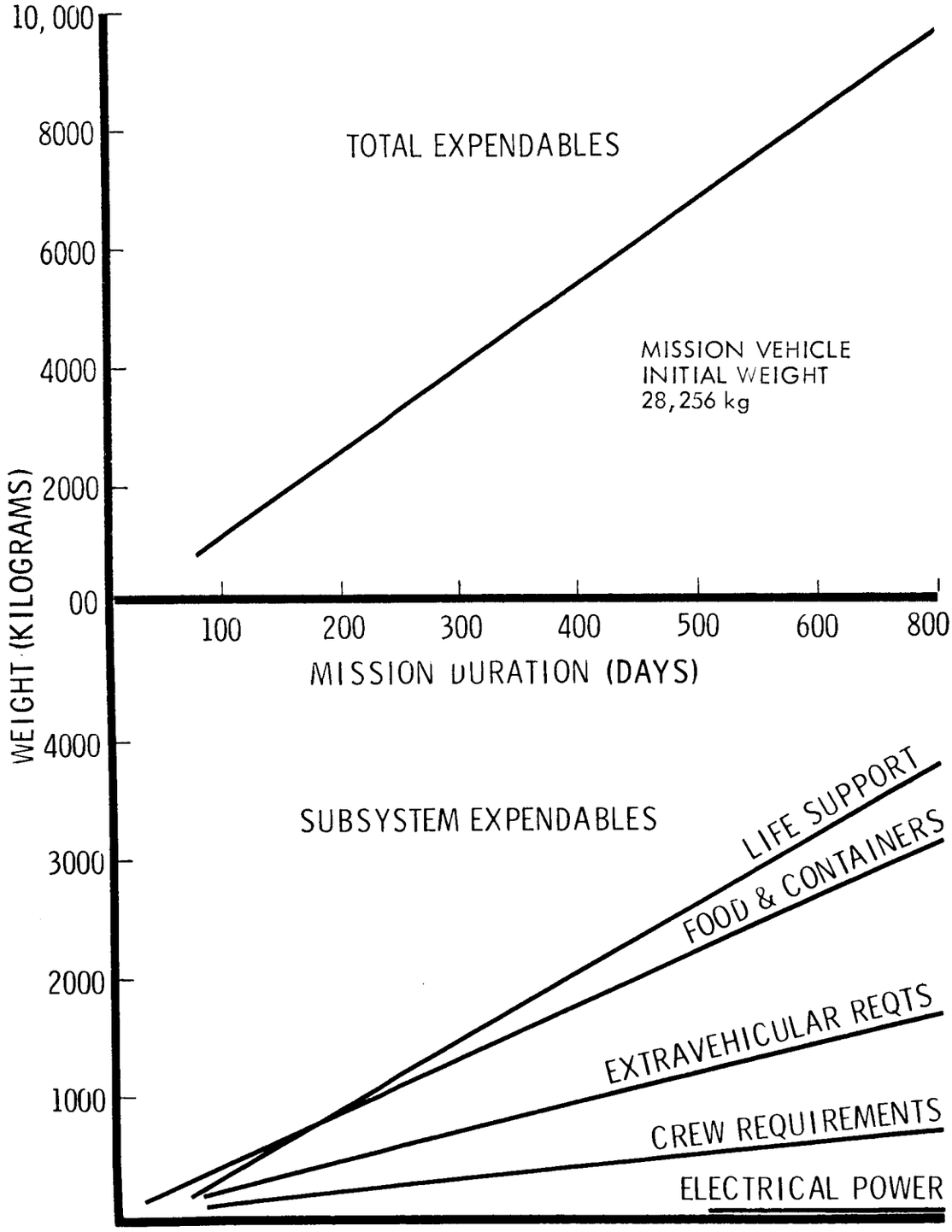


Figure 6.2-5: SUBSYSTEM EXPENDABLES REQUIREMENTS — 1975 Mars / Venus Flyby Mission

### 6.2.2 1985 MARS LANDING MISSION

Tables 6.2-6, 6.2-8, and 6.2-9 tabulate the scheduled maintenance required by subsystem, task, and skill. It can be seen by comparing Table 6.2-6 with Table 5.2-4 for the 1985 $L_1$ Libration Center mission that the requirements for the two missions (spacecraft) are quite similar. The major points of difference are in subsystems that are unique to the Mars landing mission. The maintenance resources are again identified by number on Table 6.2-6. As there are slight changes from the resources used for the 1975 missions, Table 6.2-7 is included to show the 1985 resources.

The Earth reentry vehicle will require use only at the end of the mission and periodic inspection is less frequent than for the libration center mission. The ERV will, however, require extensive checkout and preparation before Earth reentry. This period of checkout will start at least a week before the actual reentry maneuver. The checkout will be made using spacecraft power, thereby delaying battery drain until the ERV is separated from the spacecraft. Supplies, experiment data, films, and samples from the Mars surface will be loaded into the ERV after it has been checked out.

The electrical power subsystem and the propulsion system, which includes the midcourse hardware and the reaction control thrust system, will require periodic inspection. This requirement is common to the 1975 Mars/Venus flyby mission, except that the period between inspections was increased. It may be desirable to inspect the Mars capture and Mars departure propulsion modules (PM2 and PM3) before use. However, this study has not established a definite need for that action, and has not determined whether an adequate inspection can in fact be made.

The most significant single scheduled maintenance item is the laser assembly in the communications subsystem. This item is expected to have a useful life of 2000 hours. Replacement is scheduled for 90 days, which is somewhat over 2000 hours. In practice it may be proper to delay replacement until failure of the assembly or until the quality of the beam has fallen below acceptable standards. As an alternative, replacement could be planned for periods of low scientific and scheduled maintenance workload providing these periods can be found 2000 hours, or less, apart. Scheduled replacement time was estimated to be the same as unscheduled repair time, less an increment for trouble-shooting. It seems possible that the actual replacement time can be reduced by design of the transmitter structure, but this may be insignificant if automatic alignment cannot be achieved. The present task time includes a large amount of time allocated to realignment of the laser beam with the pointing and tracking equipment.

Figure 6.2-10 summarizes expendables requirements for the 1985 Mars landing mission. Details are given on a data sheet in Volume III.

Table 6.2-6: SCHEDULED MAINTENANCE - 1985 MARS LANDING MISSION

| Code | Item | Task | Time/Skill (Min.) LS | EE | ME | ST | CM | Resources |
|---|---|---|---|---|---|---|---|---|
| | | DAILY | | | | | | |
| IF | Console Displays | Check and record readings | | 10 | | | | |
| LS | Life Support System | General gross checks | 10 | | | | | |
| | | 7 DAYS | | | | | | |
| LS | Carbon Collection Bag | Replace bag(2 at 15 min. ea.) | 30 | | | | | 1,2 |
| CS | Sponge, Disinfectant, Vacuum Cleaner | General interior cleaning | 180 | | 180 | | | |
| LS | Life Support System | General inspection | 30 | | | | | |
| | | 14 DAYS | | | | | | |
| LS | Urine Filter | Replace filter (2) | 30 | | | | | |
| | | 30 DAYS | | | | | | |
| LS | Evaporation Wick | Replace wick (4) | 60 | | | | | |
| LS | Gas Chromatograph | Calibrate | | 20 | | | | |
| LS | Mass Spectrometer | Calibrate | | 20 | | | | |
| LS | Life Support System | Check instrumentation, operate manual valves | 60 | | | | | |
| CS | Vacuum Cleaner | Replace bag | | | 10 | | | |
| CS | Fire Extinguishers | Inspect | | | 30 | | | |
| ST | Structure | Inspect spacecraft exterior | | | 120 | 120 | | 1,6,15,16,17 |
| IF | Display Indicators | Replace lamp (2) | | 10 | | | | |

Table 6.2-6: SCHEDULED MAINTENANCE - 1985 MARS LANDING MISSION (Cont)

| Code | Item | Task | Time/Skill (min.) LS | EE | ME | CM | GC | ST | Resources |
|---|---|---|---|---|---|---|---|---|---|
| | | 60 DAYS | | | | | | | |
| LS | Charcoal Filter, Gas | Replace filter (4) | 60 | | | | | | 1,2 |
| LS | Charcoal Filter, Fluid | Replace filter (4) | 80 | | | | | | 1,2 |
| LS | Charcoal and Particulate Filter | Replace filter (4) | 60 | | | | | | 1,2 |
| LS | Absolute Filter | Replace filter (2) | 30 | | | | | | 1,2 |
| LS | Catalytic Filter | Replace cartridge (4) | 80 | | | | | | 1,2 |
| EP | Power Generation Bay | Inspect Brayton machinery | | 90 | 90 | | | | 15,16,17 |
| PP | Midcourse Engines and RCS | Inspect | | | 120 | | | 120 | 15,16,17 |
| | | 90 DAYS | | | | | | | |
| LS | Conductivity Sensor | Calibrate (4) | | 80 | | | | | 1,9 |
| LS | Odor Filter | Replace filter (2) | 40 | | | | | | 1,2 |
| LS | $O_2$ Partial Pressure Sensor | Replace element (4) | 40 | | | | | | 1 |
| LS | $CO_2$ Partial Pressure Sensor | Replace element (4) | 40 | | | | | | 1 |
| CM | Laser Assembly | Replace | | 400 | | 400 | | | 1,3,11,15-19 |
| CS | Film Viewer | Inspect and clean | | 15 | | | | | 1,2 |
| CS | Microfilm Reader | Inspect and clean | | 15 | | | | | 1,2 |
| CS | Lamp, Incandescent | Replace | | 10 | | | | | |
| CS | Lamp, Fluorescent | Replace (2) | | 40 | | | | | |
| DM | Typewriter | Clean | | 30 | | | | | 1,2 |
| DM | Console Viewer | Inspect and clean | | 15 | | | | | 1,2 |
| DM | Film Projector and Scanner | Inspect and clean | | 15 | | | | | 1,2 |
| EX | Experiment Airlock | Lubricate | | | 30 | | | | 1,12 |
| RE | Earth Reentry Vehicle | Inspection and checkout | 30 | 60 | | 60 | 60 | | 1,2 |
| EV | Module Airlock | Lubricate | | | 30 | | | | 1,12 |
| ST | Docking Systems | Inspect and lubricate | | | 90 | | | 90 | 1,12,15,16,17 |
| | | 360 DAYS | | | | | | | |
| EP | Voltage Regulator | Replace | | 120 | | | | | 1,11 |

Table 6.2-7: MAINTENANCE RESOURCE CODE IDENTIFICATION
1985 MARS LANDING MISSION

| Maintenance Resource | Code Number |
|---|---|
| Standard Tool Kit | 1 |
| Vacuum System | 2 |
| Space Power Tool Kit | 3 |
| Electron-Beam Welder | 4 |
| Stemfab Tool | 5 |
| Leak Detection Equipment | 6 |
| Temperature Measuring Device | 7 |
| Pressure Measuring Device | 8 |
| Water Test Kit | 9 |
| Battery Test Kit | 10 |
| Electrical Repair Kit | 11 |
| Lubrication Kit | 12 |
| Fabric Repair Kit | 13 |
| Airflow Meter | 14 |
| Safety Devices | 15 |
| Powered Locomotion Devices | 16 |
| Manual Locomotion and Restraint | 17 |
| Insulation Repair Kit | 18 |
| Spare Fitting Kit | 19 |
| Spacesuit Repair Kit | 20 |
| Life Support System Repair Skill | 51 |
| Electrical/Electronic Repair Skill | 52 |
| Mechanical Repair Skill | 53 |
| Structural Repair Skill | 54 |
| Communications Repair Skill | 55 |
| Guidance and Control Repair Skill | 56 |
| Medical Skill | 57 |
| Scientist-Experimental Skill | 58 |

Table 6.2-8: SUBSYSTEM SCHEDULED MAINTENANCE REQUIREMENTS - 1985 MARS LANDING MISSION

| Subsystem | Man-Minutes/Maintenance Interval (days) 1 | 7 | 14 | 30 | 60 | 90 | Average Man-Minutes/Day |
|---|---|---|---|---|---|---|---|
| Life Support | 10 | 60 | 30 | 160 | 310 | 200 | 33.4 |
| Communications | | | | | | 800 | 8.9 |
| Crew System | | 360 | | 40 | | 80 | 53.8 |
| Data Management | | | | | | 60 | 0.7 |
| Electrical Power | | | | | 180 | | 3.0 |
| Extravehicular Activity | | | | | | 30 | 0.3 |
| Experiments | | | | | | 30 | 0.3 |
| Inflight Test | 10 | | | 10 | | | 10.3 |
| Propulsion | | | | | 240 | | 4.0 |
| Earth Reentry Vehicle | | | | | | 210 | 2.3 |
| Structure | | | | 240 | | 180 | 10.0 |
| Total Man-Minutes | 20 | 420 | 30 | 450 | 730 | 1590 | |
| Average Man-Minutes/Day | 20 | 60 | 2.1 | 15 | 12.2 | 17.7 | 127.0 |

NOTE: Scheduled maintenance required at intervals greater than 90 days is not shown in the above summary because these tasks must be accomplished at about the time indicated and cannot be apportioned over a number of days as indicated by the averages above. Similarly, scheduled tasks required during Mars orbit, MEM preparation, and before Earth reentry are not indicated above.

Table 6.2-9: SCHEDULED MAINTENANCE CREW SKILL REQUIREMENTS - 1985 MARS LANDING MISSION

| Skill | Man-Minutes/Maintenance Interval (Days) 1 | 7 | 14 | 30 | 60 | 90 | Average Man-Minutes/Day |
|---|---|---|---|---|---|---|---|
| Life Support Systems | 10 | 240 | 30 | 120 | 310 | 150 | 57.3 |
| Electrical/Electronic | 10 | | | 50 | 90 | 680 | 20.8 |
| Mechanical | | 180 | | 160 | 210 | 150 | 36.2 |
| Guidance and Control | | | | | | 60 | 0.7 |
| Structures | | | | 120 | 120 | 90 | 7.0 |
| Communications | | | | | | 460 | 5.0 |
| Total Man-Minutes | 20 | 420 | 30 | 450 | 730 | 1590 | |
| Average Man-Minutes/Day | 20 | 60 | 2.1 | 15 | 12.2 | 17.7 | 127.0 |

NOTE: Scheduled maintenance required at intervals greater than 90 days is not shown in the above summary because these tasks must be accomplished at about the time indicated and cannot be apportioned over a number of days as indicated by the averages above. Similarly scheduled tasks required during Mars orbit, MEM preparation, and before Earth reentry are not indicated above.

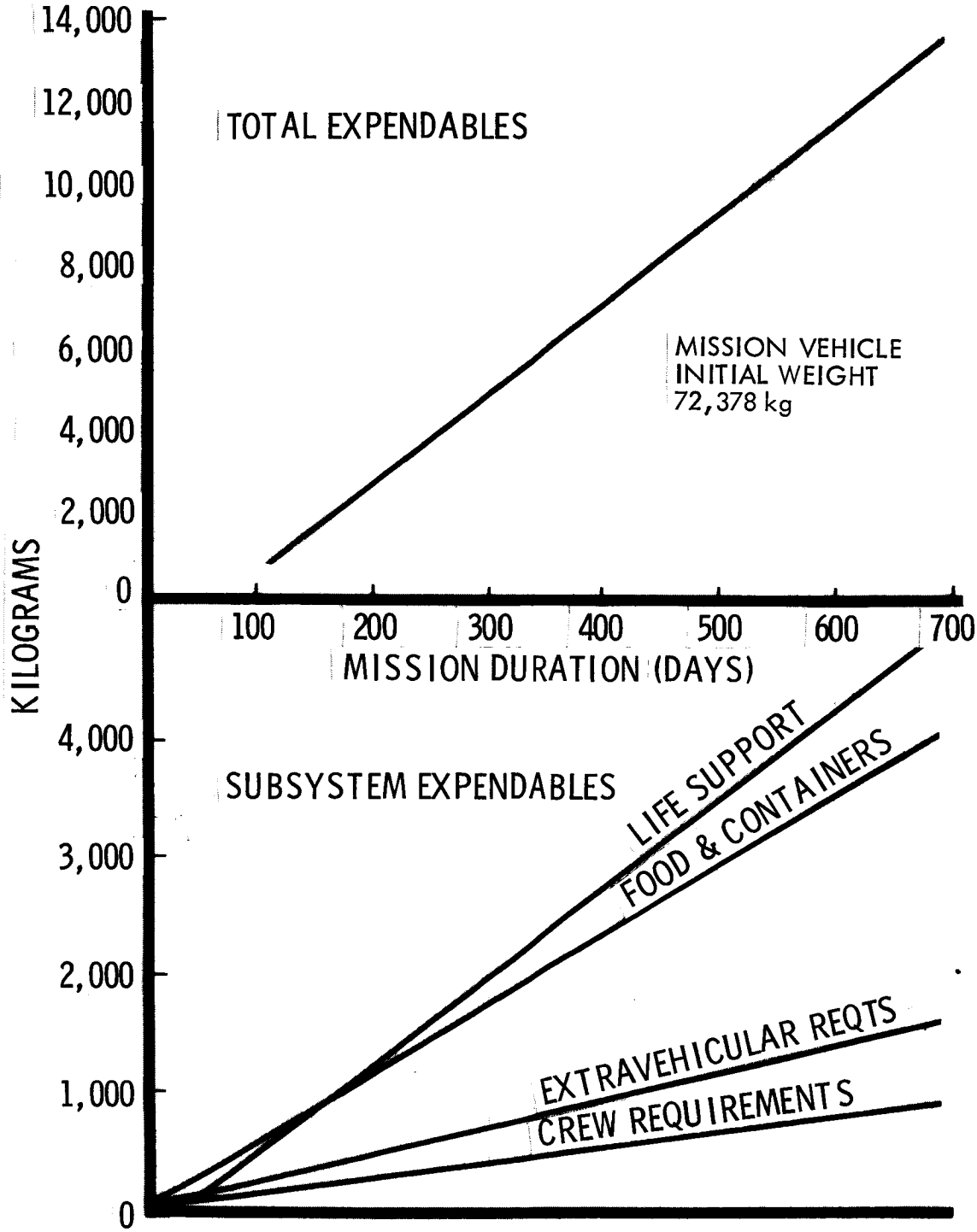


Figure 6.2-10: SUBSYSTEM EXPENDABLES REQUIREMENTS — 1985 Mars Landing Mission

## 6.3 EFFECTS OF UNSCHEDULED MAINTENANCE ON OVERALL MISSION REQUIREMENTS

A mission simulation model (described in Section 3.4) was used to determine the unscheduled maintenance requirements of the spacecraft and find expected effects of maintenance time, spares weight used, reliability, and maintenance resources on the mission. The spacecraft configuration simulated was the same basic configuration optimized by the MARCEP analysis (Section 3.5). For the simulation the fixed redundancies (parallel and standby redundancies) identified by MARCEP were included in the configuration analyzed and allowed to fail randomly. When an element of a redundant set failed it was repaired with a spare if repair was allowable. Repair times were assumed to be distributed log-normally about the mean repair time specified for each repairable component on the MARCEP and maintenance task analysis sheets (included in Volume III). Selection of specific repair times in the simulations was done randomly.

The information presented in the following sections is based on at least 100 simulations of each mission time. By performing many simulations, an authoritative statistical base of expected unscheduled maintenance activities was established. From the simulations crew skill requirements, subsystem unscheduled maintenance requirements, spares use, distributions of repair task times and daily maintenance times, airlock use, and spacesuit use for unscheduled maintenance were determined for each of the planetary class of missions.

### 6.3.1 1975 MARS/VENUS FLYBY MISSION

Unscheduled maintenance requirements according to skill required and according to subsystem are shown in Tables 6.3-1 and 6.3-2. As indicated by the first table, the average daily demands on any one skill are minimal. The highest demands are required of the electrical/electronic and mechanical skills with 20.2 and 10.9 minutes/day average workload, respectively. However, the average skill use time for any discrete task taken at random is 186 minutes; this figure considers both interior and exterior tasks. The average daily workload is calculated by dividing the average skill use time by the mean time between skill uses. Table 6.3-2 shows the unscheduled maintenance requirements by subsystem. When this and the previous table are compared, differences in the accumulated averages can be noted. The differences are because the subsystem table, (Table 6.3-2) includes tasks that require more than one workman employing simultaneous or overlapping skills. If each task had required only one repairman, the totals on each table would be exactly the same. Figure 6.3-3 is a graphic presentation of Table 6.3-2.

In studying such complex missions, it is risky to plan on the basis of averages alone. Averages do not give adequate visibility to queuing (the delays caused by required resources being used on other tasks). It was found that in 100 missions the life support skill was queued for three times with an average delay of 32 minutes. More significant were the queues for electronic and mechanical skills. The electrical/electronic skill was queued for 112 times, or slightly over once per mission. The average delay for this skill was 498 minutes. The mechanical skill was queued for 16 times with an average

Table 6.3-1: UNSCHEDULED MAINTENANCE CREW SKILL REQUIREMENTS---
1975 MARS/VENUS FLYBY MISSION

| Crew Skill | % of Total Repair Time | Mean Days Between Skill Use | Average Min./Skill Use | Average Min./Day |
|---|---|---|---|---|
| Life Support Systems | 8.7 | 36.8 | 142 | 3.9 |
| Electrical/Electronic | 45.4 | 7.5 | 152 | 20.2 |
| Mechanical | 24.4 | 31.1 | 338 | 10.9 |
| Structures | 7.9 | 74.9 | 260 | 3.5 |
| Communications | 6.5 | 57.0 | 164 | 2.9 |
| Guidance and Control | 5.4 | 76.1 | 180 | 2.4 |
| Medical | 0.6 | 27,500.0 | 770 | 0.03 |
| Scientist-Experiments | 1.1 | 524.0 | 480 | 0.92 |
| Totals | 100.0 | 4.26 Average | 186 Average | 44.8 |

NOTE: The above data is based on one hundred 550-day simulation runs, which is the equivalent of 150 years of operation.

Table 6.3-2: SUBSYSTEM UNSCHEDULED MAINTENANCE REQUIREMENTS---
1975 MARS/VENUS FLYBY MISSION

| Subsystem | Percent of Total System Failures | Percent of Total System Repair Time | Mean Days Between Failures | Average Min./Fail. | Average Min./Day |
|---|---|---|---|---|---|
| Life Support | 12.88 | 11.73 | 36.52 | 143 | 3.92 |
| Communications | 3.76 | 6.92 | 122.12 | 282 | 2.31 |
| Crew System | 0.14 | 0.06 | 3,437.50 | 69 | 0.02 |
| Data Management | 44.26 | 29.58 | 10.62 | 105 | 9.89 |
| Electrical Power | 4.15 | 5.20 | 113.64 | 198 | 1.74 |
| Extravehicular Activity | 0.27 | 0.33 | 1,774.19 | 188 | 0.11 |
| Experiments | 0.69 | 2.48 | 679.01 | 562 | 0.83 |
| Inflight Test | 11.94 | 6.16 | 39.40 | 81 | 2.06 |
| Maintenance Equipment | 0.05 | 0.06 | 11,000.00 | 175 | 0.02 |
| Propulsion System | 8.12 | 12.86 | 57.89 | 249 | 4.30 |
| Earth Reentry System | 0.26 | 0.72 | 1,833.33 | 442 | 0.24 |
| Stability and Control | 6.05 | 6.61 | 77.79 | 172 | 2.21 |
| Structure | 0.27 | 0.72 | 1,774.19 | 429 | 0.24 |
| Navigation and Guidance | 7.16 | 16.57 | 65.71 | 364 | 5.54 |
| Totals | 100.00 | 100.00 | 4.69 Average | 161 Average | 33.43 |

Note: The above data is based on one hundred 550-day simulation runs, which is the equivalent of 150 years of operation.

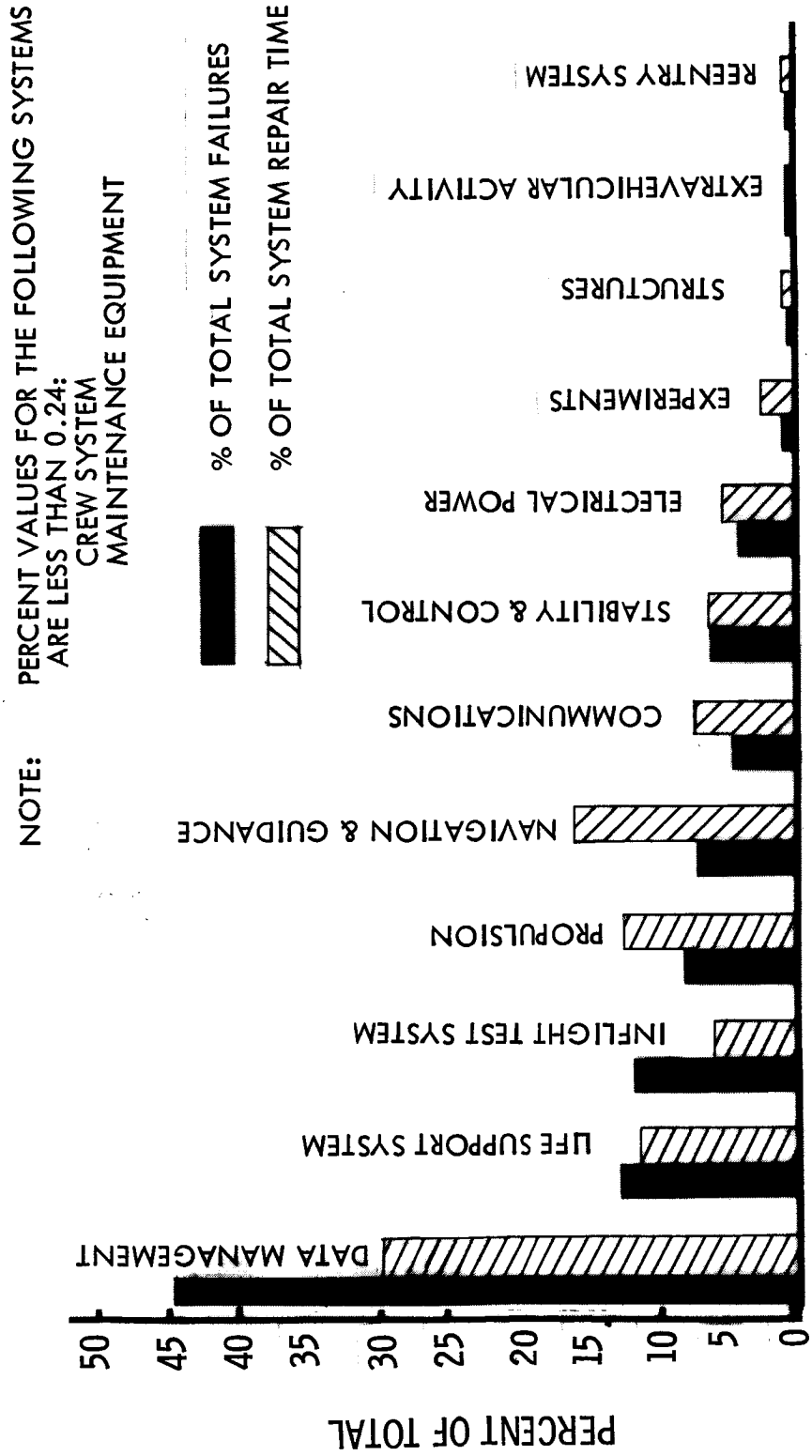


Figure 6.3-3: SUBSYSTEM FAILURES AND UNSCHEDULED MAINTENANCE REPAIR TIME — 1975 Mars/Venus Flyby Mission

delay of 663 minutes. Although at first glance this may seem excessive when related to the average skill use time of 338 minutes (Table 6.3-1), it can be explained by noting that the average use time was developed from nearly 1800 discrete mechanical skill requirements throughout 100 missions, wherein a waiting period occurred on only 16 occasions. These occasions may have entailed multiple queuing for the same skill, chance selections of repair time requirements in the higher regions of the log-normal distribution curve, or a combination of these factors. The only other skill queue recorded was for the communications skill, which was queued for six times with an average delay of 271 minutes. Some queues for hardware resources also were found. The major item was a queue of 69 times for the electrical repair kit. The average delay for this was 492 minutes. This seems reasonable because in most cases the electrical/electronic skill (repairman) will be using the kit, therefore, the queuing for the skill and for the kit are parallel rather than series queues. Also, the figure can be rationalized in the same way as for the mechanical skill queuing, considering that there were more than 9000 separate requirements during the 100 simulated missions. The information indicates that queuing will not be a major problem; however, cross-training would be desirable and the first skill to be cross-trained would be the electrical/electronic skill. This skill should be cross-trained with one of the low-demand skills such as guidance and control or scientific.

Figures 6.3-4 and 6.3-5 show the cumulative probability of spares use by weight and volume for 450-, 550-, and 650-day missions. The range of values and probability numbers represent what could be expected to occur in 150 years of operation. By selecting the 95% cumulative probability point and reading spares weight used, one can state with 95% confidence that the indicated weight of spares, or less, will be used for that mission. By comparing the 95% confidence level of spares weight used with the spares weight allocated by the MARCEP analysis (Figure 6.1-1), it is found that about 15% of the MARCEP allocated spares are actually used. The mean spares use is found to be about 7.5% in a similar manner.

The irregularities in both the weight and volume curves of Figures 6.3-4 and 6.3-5 are caused by relatively heavy, high volume, items. When these items are consumed, weight and volume increase rapidly with a small increase in the cumulative use probability. As mission times are increased the probability of using the heavy items increases and the curves will acquire a smoothing trend.

The daily repair time distribution for unscheduled maintenance is shown by Figure 6.3-6. No unscheduled maintenance is required on 80.4% of the mission days, as shown in the figure. This compares well with the 1975 near-Earth mission that showed 86.2% of the mission days requiring no unscheduled maintenance. The mean of the distribution was found to be 47 man-minutes per day.

Figure 6.3-7 shows the distribution of task times for the days on which unscheduled maintenance occurred. The figure indicates that the mean for all tasks performed was 2.75 hours (161 minutes) per task. The largest task time recorded was 100 hours. This occurred during replacement of the inertial platform. The normal replacement time for the item is 10 hours and requires two

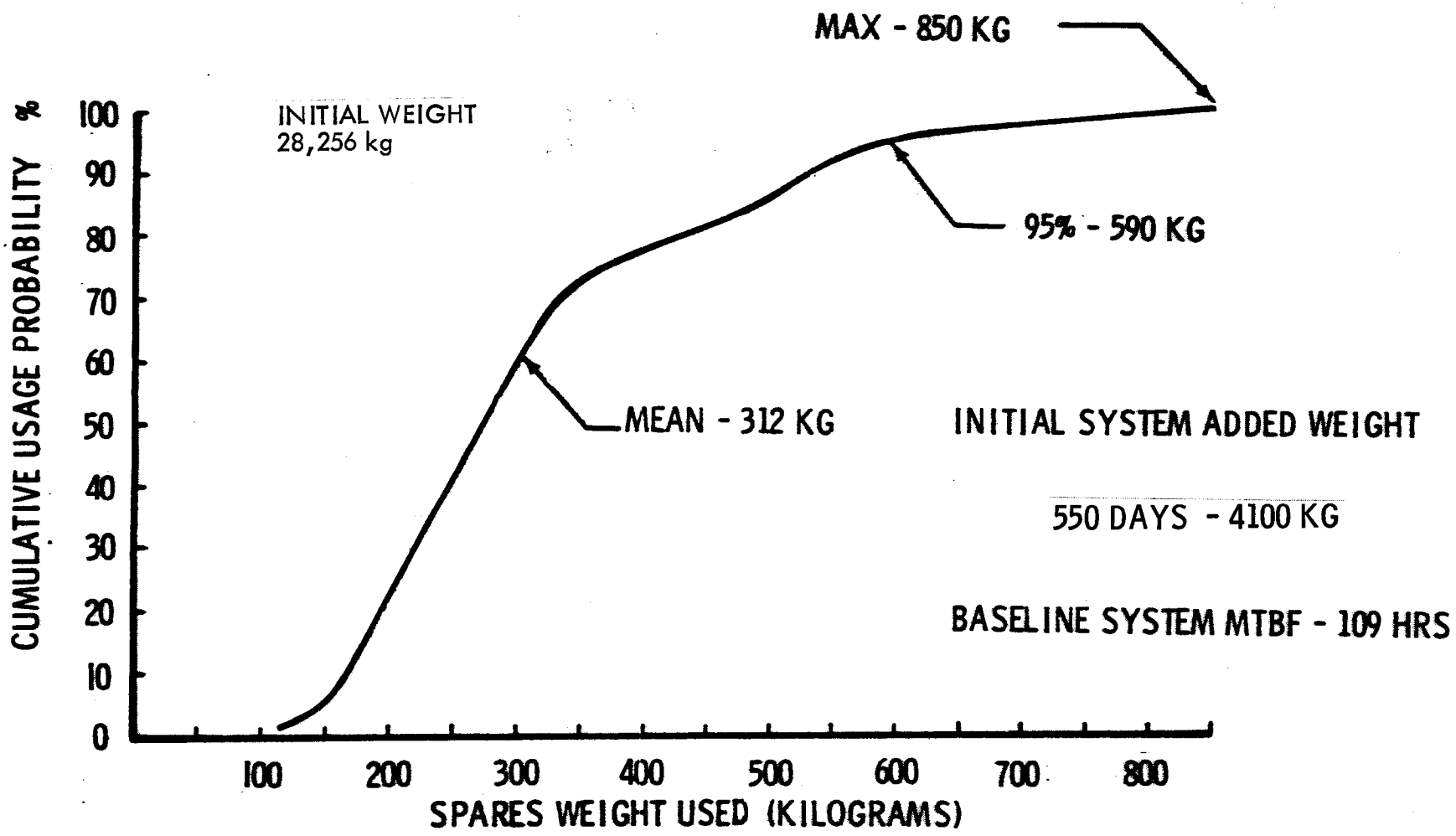


Figure 6.3-4: SPARES WEIGHT USAGE PROBABILITY
1975 Mars/Venus Flyby Mission

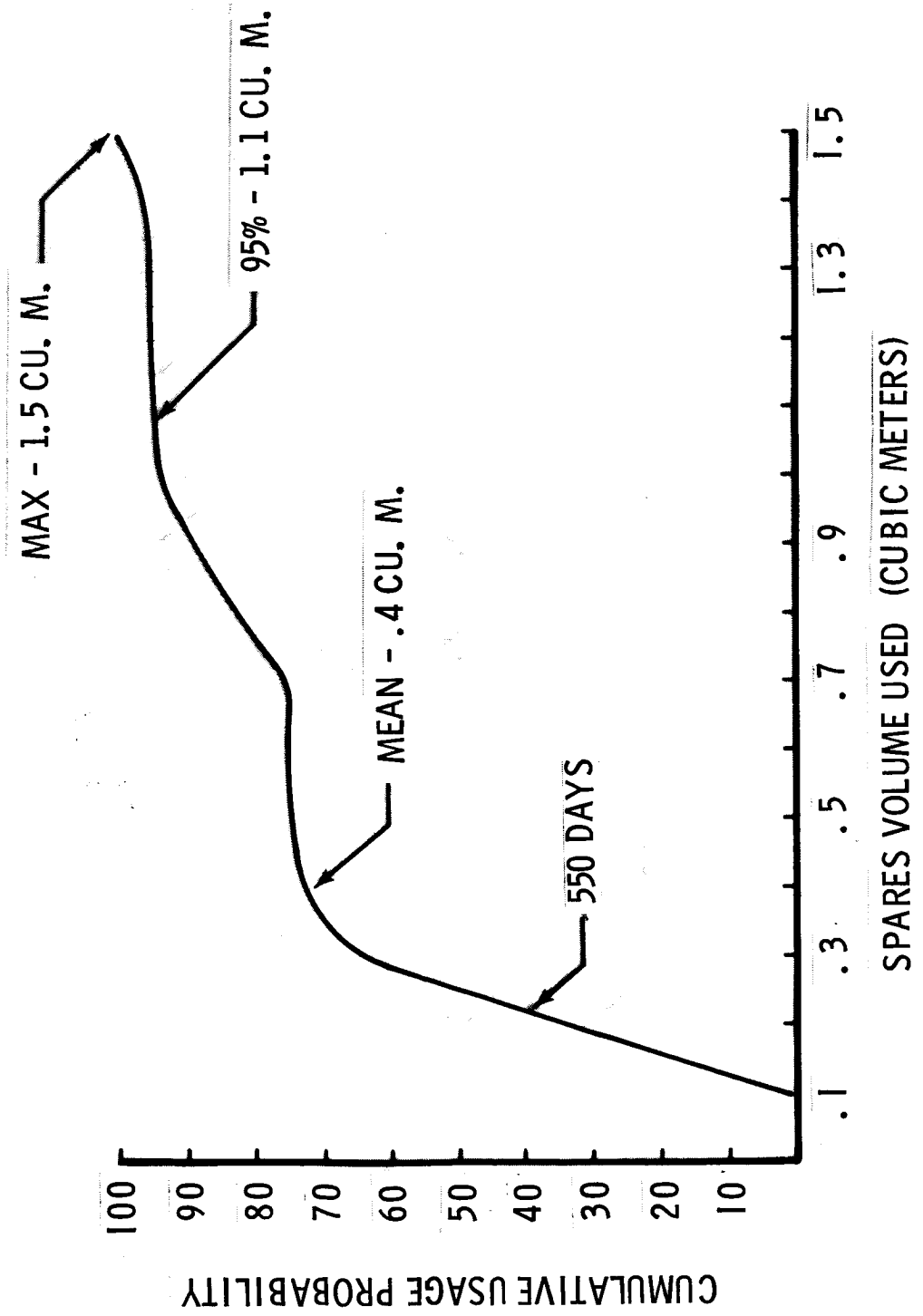


Figure 6.3-5: SPARES VOLUME USAGE PROBABILITY — 1975 Mars/Venus Flyby Mission

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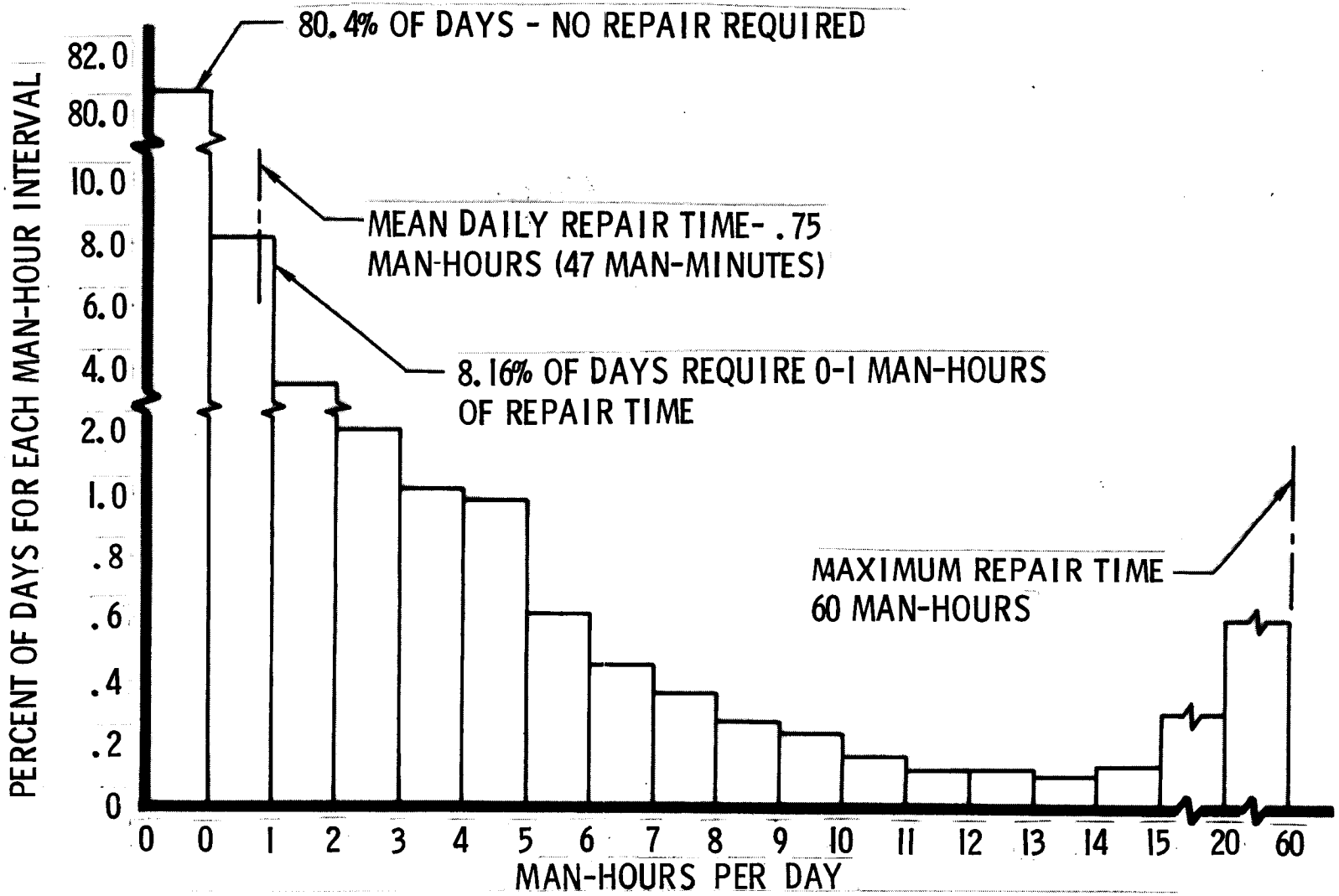


Figure 6.3-6: UNSCHEDULED MAINTENANCE DAILY REPAIR TIME DISTRIBUTION — 1975 Mars/Venus Flyby Mission

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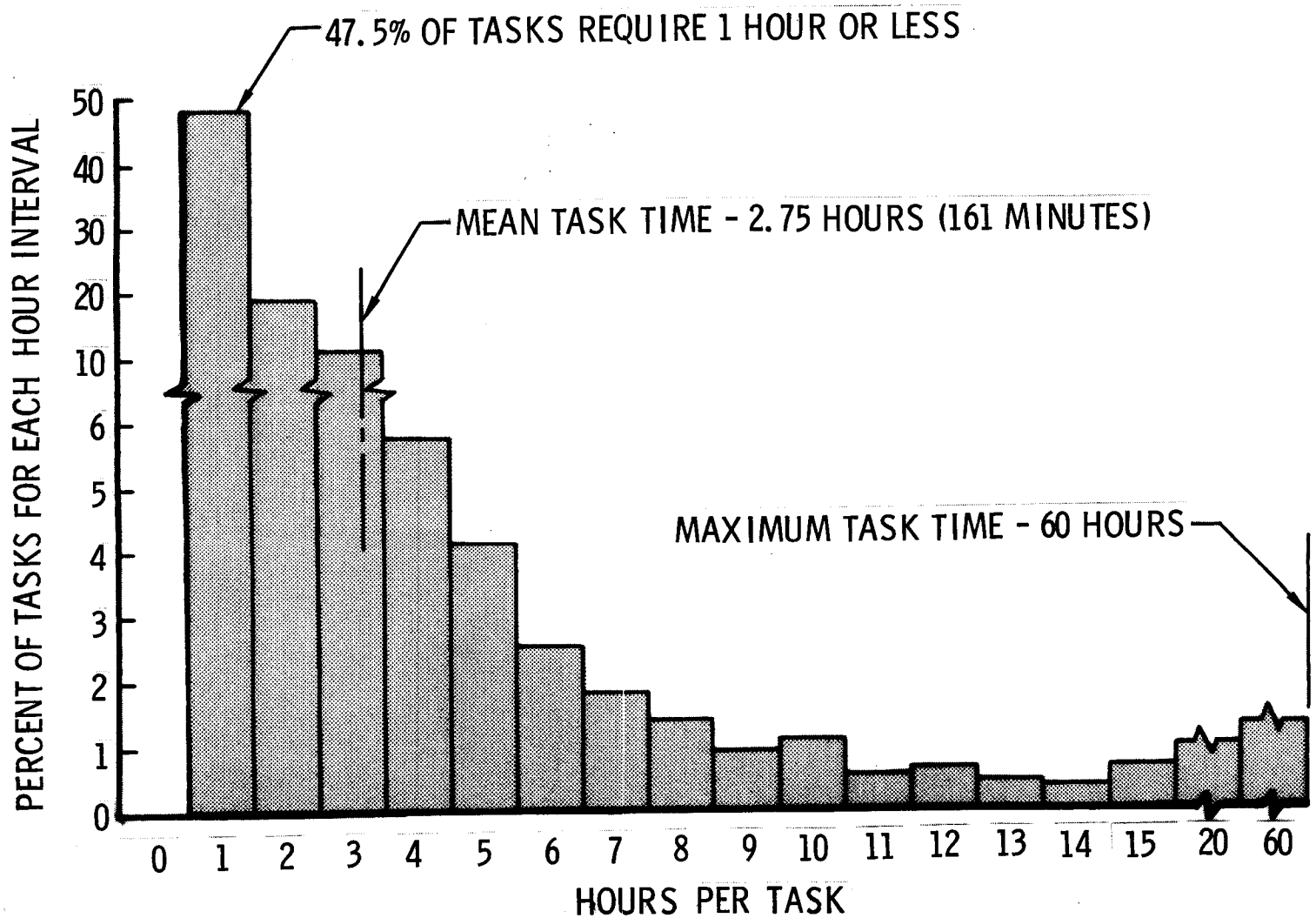


Figure 6.3-7: UNSCHEDULED MAINTENANCE REPAIR TASK TIME DISTRIBUTION —1975 Mars/Venus Flyby Mission

men. The replacement time includes fault isolation to the platform itself and alignment of the new unit after replacement. By chance, the task time determined for this item when it failed happened to be 10 times the expected normal requirement. One can rationalize that the extreme task time was due to problems in isolating the fault to the platform and difficulties in getting the new platform aligned.

The distribution of airlock uses for unscheduled maintenance for the 550-day mission is shown by Figure 6.3-8. The mean number of uses for all the simulation runs was 28 uses per mission. The 95th percentile of the distribution was found to be 48 uses per mission, which means that 95% of all missions will require no more than 48 airlock uses for unscheduled maintenance. One airlock use is assumed to be a complete egress-ingress cycle for two extravehicular repairmen.

Manhours of spacesuit use for unscheduled maintenance are shown by Figure 6.3-9. All tasks external to the pressurized areas are assumed to require two men for safety purposes. In some cases two and even three men are required to perform the maintenance task. This is reflected in the distribution of spacesuit manhours of use. The mean spacesuit use was found to be 120 manhours of use per mission.

### 6.3.2 1985 MARS LANDING MISSION

Unscheduled maintenance requirements for the 1985 Mars landing mission are shown in Tables 6.3-10 and 6.3-11. The general description of these tables is the same as provided for the 1975 mission in Section 6.3.1. It is interesting to note that percent of total repair time accrued by each skill showed a leveling trend in Table 6.3-10, in comparison with the trend for the 1975 mission shown in Table 6.3-1. The most probable explanation is that improvements for the 1985 time period in components with high failure rates during the 1975 mission caused most of the leveling, and the reduction in repair time for the more lengthy tasks accounted for the rest of the leveling. Unexpectedly, the total average minutes/skill use in Table 6.3-10 increased from the 186 minutes/skill use shown for the 1975 mission. It has been determined that this was caused by elimination of many short duration tasks performed in the 1975 mission, thus biasing the average upwards. The trend in the average minutes per day and in the mean days between tasks was downward as expected. The medical skill showed a significant decrease. This was because the skill was used to assist in maintenance on the biological probes carried on the Mars/Venus flyby mission, and on the 1985 mission this would not be a requirement.

The trends shown in Table 6.3-11 are as expected. It can be seen that there appears to be a discrepancy in the last three entries for the propulsion systems. This is because the propulsion system experienced a significant number of failures that were not repairable. Average minutes per failure should be read in this case as average minutes per repairable failure. All of the failures noted as nonrepairable were in items with redundancies provided. The highest number of such failures were noted for the tank bladders that were added within the tanks as fixed redundancies during the MARCEP analysis runs made previously. Figure 6.3-12 is a graphic presentation of the information shown in Table 6.3-11.

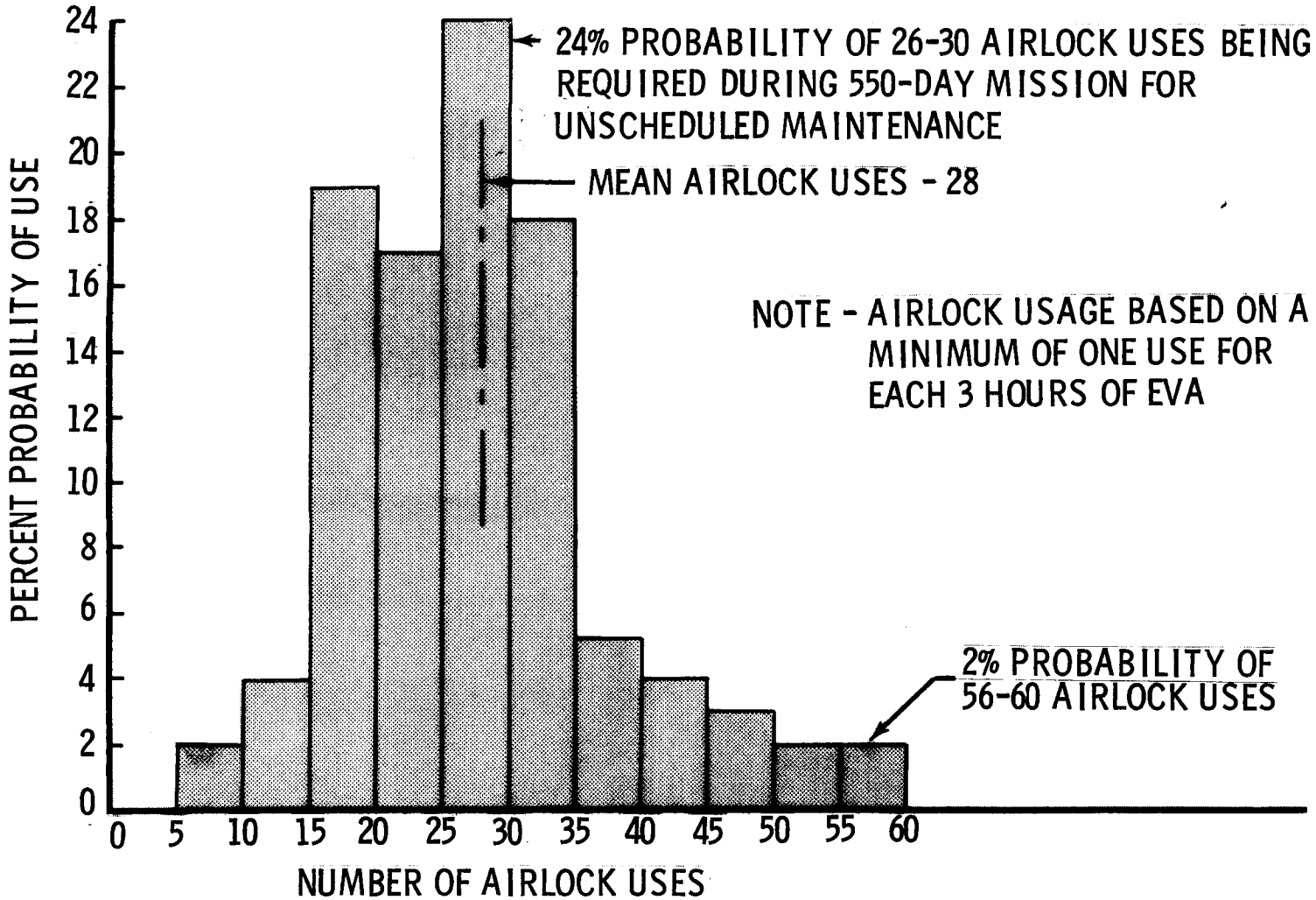


Figure 6.3-8: UNSCHEDULED MAINTENANCE AIRLOCK USAGE DISTRIBUTION — 1975 Mars/Venus Flyby Mission

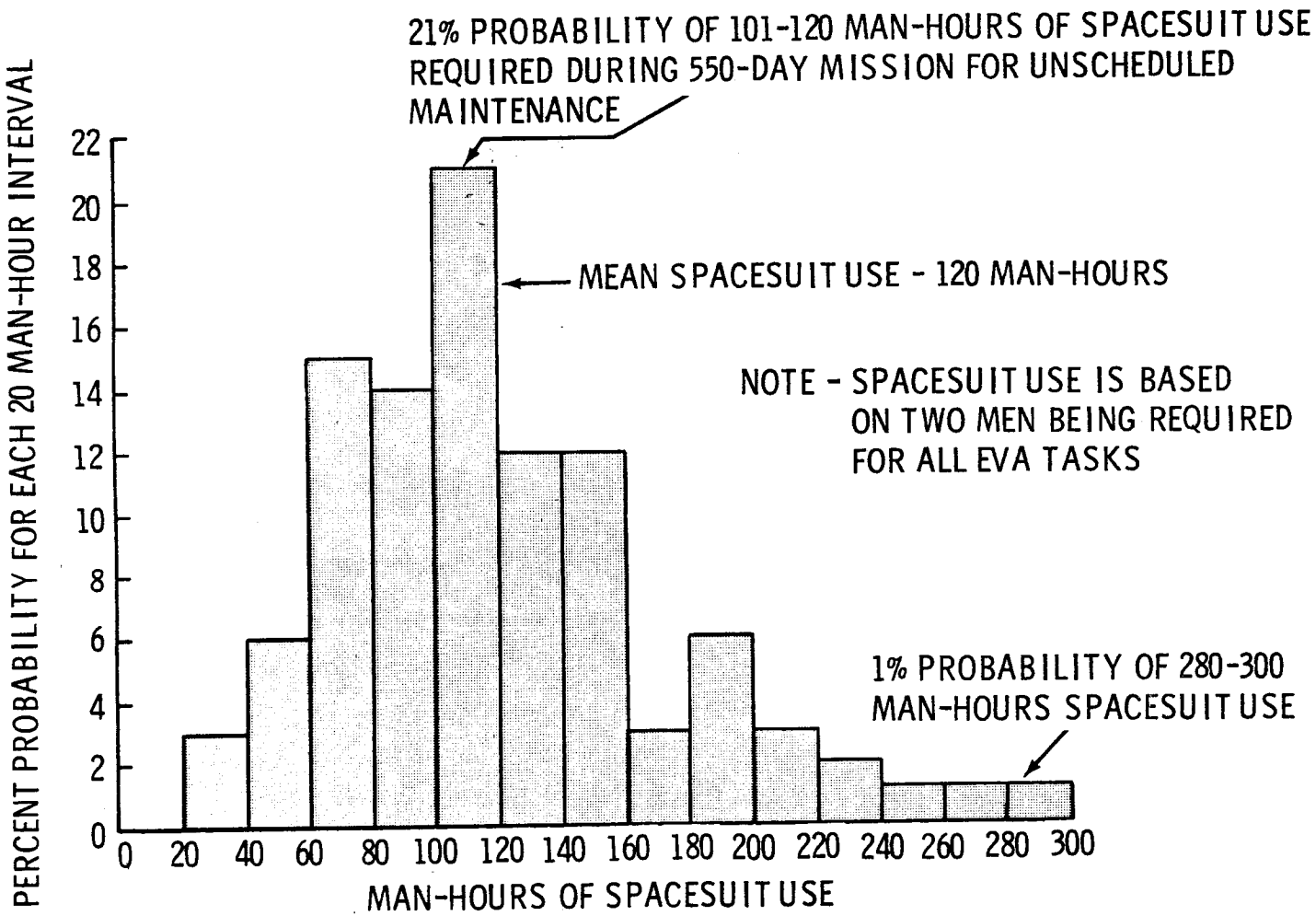


Figure 6.3-9: UNSCHEDULED MAINTENANCE SPACESUIT USAGE DISTRIBUTION — 1975 Mars / Venus Flyby Mission

Table 6.3-10: UNSCHEDULED MAINTENANCE CREW SKILL REQUIREMENTS---
1985 MARS LANDING MISSION

| Crew Skill | % of Total Repair Time | Mean Days Between Skill Use | Average Min./Skill Use | Average Min./Day |
|---|---|---|---|---|
| Life Support Systems | 21.7 | 38 | 144 | 3.79 |
| Electrical/Electronic | 28.8 | 27 | 136 | 5.04 |
| Mechanical | 28.1 | 79 | 389 | 4.92 |
| Structures | 9.3 | 442 | 716 | 1.62 |
| Communications | 3.8 | 271 | 180 | 0.66 |
| Guidance and Control | 7.1 | 135 | 168 | 1.24 |
| Medical | 0.0 | 46,000 | 6 | --- |
| Scientist-Experiments | 1.2 | 1,022 | 215 | 0.21 |
| Totals | 100.0 | 10.95 Average | 191 Average | 17.48 |

Note: The above data is based on one hundred 460-day simulation runs, which is the equivalent of 126 years of operation.

Table 6.3-11: SUBSYSTEM UNSCHEDULED MAINTENANCE REQUIREMENTS---
1985 MARS LANDING MISSION

| Subsystem | Percent of Total System Failures | Percent of Total System Repair Time | Mean Days Between Failures | Average Min./Fail. | Average Min./Day |
|---|---|---|---|---|---|
| Life Support | 41.48 | 37.43 | 28 | 141 | 5.03 |
| Communications | 5.29 | 14.54 | 220 | 430 | 1.95 |
| Crew System | 0.66 | 0.27 | 1769 | 63 | 0.04 |
| Data Management | 3.82 | 3.86 | 305 | 158 | 0.52 |
| Electrical Power | 6.20 | 11.26 | 188 | 284 | 1.51 |
| Extravehicular Activity | 0.48 | 1.11 | 2421 | 361 | 0.15 |
| Experiments | 1.24 | 1.71 | 939 | 216 | 0.23 |
| Inflight Test | 30.40 | 16.21 | 38 | 83 | 2.18 |
| Maintenance Equipment | 0.56 | 1.08 | 2091 | 304 | 0.15 |
| Propulsion | 2.68 | 2.30 | 434 | 273 | 0.31 |
| Earth Reentry System | 0.53 | 1.02 | 2190 | 300 | 0.14 |
| Stability and Control | 0.91 | 4.42 | 1278 | 707 | 0.55 |
| Structure | 0.81 | 2.00 | 1438 | 387 | 0.27 |
| Navigation and Guidance | 4.94 | 3.09 | 236 | 98 | 0.42 |
| Totals | 100.00 | 100.00 | 11.64 Average | 118 Average | 13.45 |

Note: The above data is based on one hundred 460-day simulation runs, which is the equivalent of 126 years of operation.

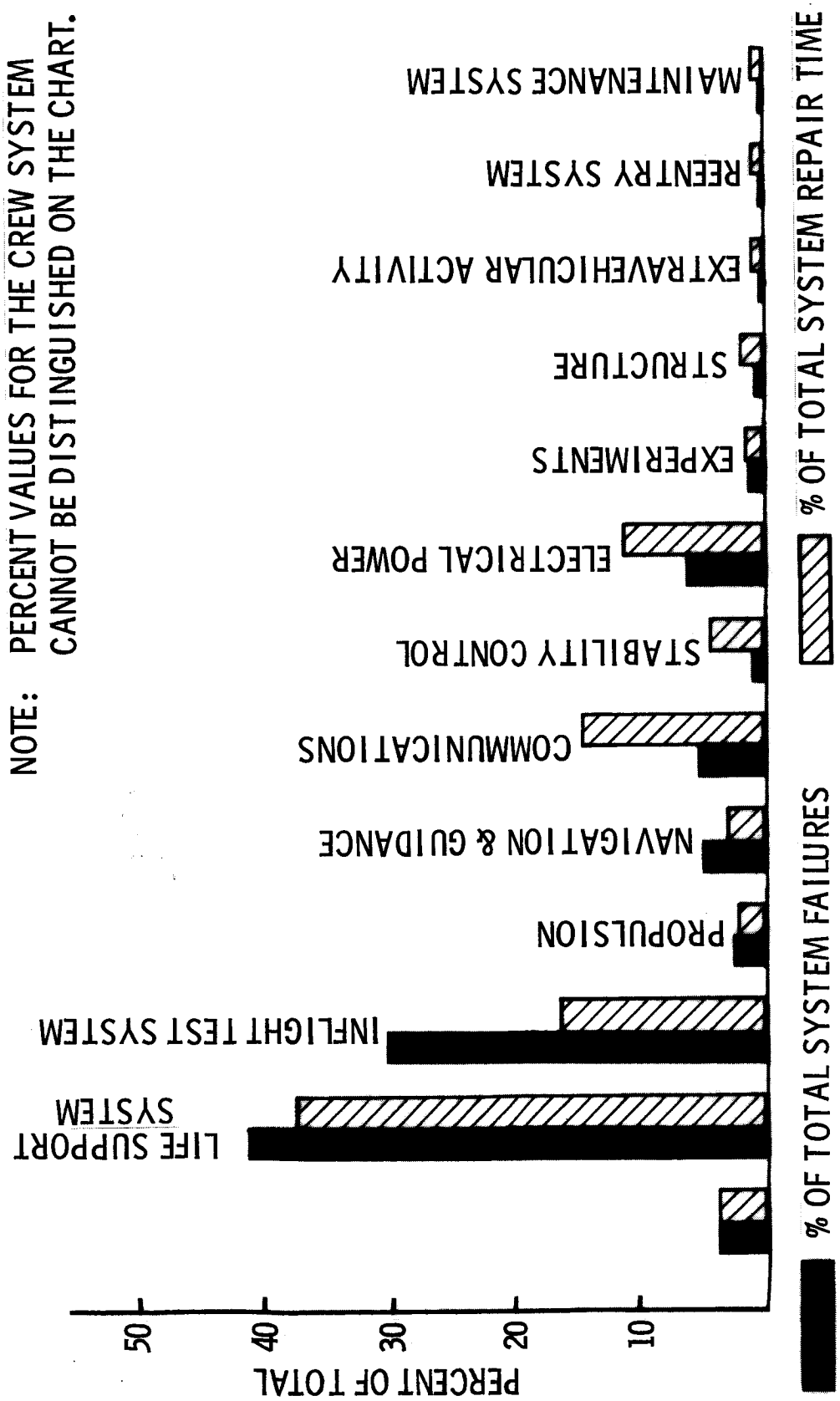


Figure 6.3-12: SUBSYSTEM FAILURES AND UNSCHEDULED MAINTENANCE REPAIR TIME — 1985 Mars Landing Mission

Queuing also was reduced below that shown for the 1975 mission. LS, E/E, ME, and G&C skills were queued for 2, 4, 3, and 1 times, respectively. The average delay times for each queue recorded were 123, 659, 490, and 60 minutes for the respective systems. Again, the most promising field for cross-training is the electrical/electronic skill field. The general problem of queuing is even less important than it was for the 1975 mission. Hardware queues were shown for the vacuum system and the electrical repair kit only; these queued 4 and 3 times, respectively, with average delay times of 536 and 380 minutes. In actual practice the vacuum system would not be used throughout a single repair task and could be shared between tasks. Also, it will probably be a built-in system with multiple intake connections, and could be used for a variety of purposes simultaneously.

Figure 6.3-13 shows the spares use for the 1985 Mars landing mission. This curve can be compared with the curves for the 1975 Mars/Venus flyby mission, Figure 6.3-4. The mean of the usage curve for 1985 is less than half that for the 450-day mission simulated in the 1975 analysis. A better point of comparison is the 95 percentile point that shows that 340-kilogram use is expected for 1985 versus 520 for the 1975 450-day simulation. This is a 35% decrease from the 1975 value. The improvement is caused by improved failure rates and low component weights as well as modularization of some system elements. The maximum weight of spares used on any of the 100 simulated missions was 490 kilograms, which is a 32% decrease below the 1975 value.

Figure 6.3-14 shows the daily repair time distribution determined by the simulation of the 1985 Mars landing mission. As indicated on the figure, no maintenance will be required on approximately 92% of the mission days. One manhour or less maintenance time will be required on 3.5% of the mission days and 4.2% of the days will require over 1 manhour of maintenance. In the simulation of the 1975 mission, approximately 10% of the mission days required more than 1 manhour of maintenance time. It should be remembered that the maintenance times discussed here, in fact all the maintenance times determined by the simulation runs, are unscheduled maintenance times. This unscheduled workload is in addition to the scheduled maintenance and servicing, which is known and planned for. When comparing the unscheduled with the scheduled workload, the unscheduled work load appears to be insignificant. The mean unscheduled workload distributed over all the mission days is 18 man-minutes per day.

On the 8% of the mission days that required maintenance, it was found that 50% of these days required tasks that took 1 hour or less, as illustrated by Figure 6.3-15. It is interesting to note that the 50 percentile point is at 1 hour, although the mean task time is at 2.6 hours. In this case there are a few infrequent long task times that increase the mean. These longer times are evident at the far right of the distribution. Representative of this is the 1% probability of encountering a task that takes between 20 and 60 hours. On the average, one might expect this to occur once every 100 missions.

Figure 6.3-16 shows the number of airlock uses that can be expected per 460-day mission. As indicated, 6% of the missions recorded no airlock uses

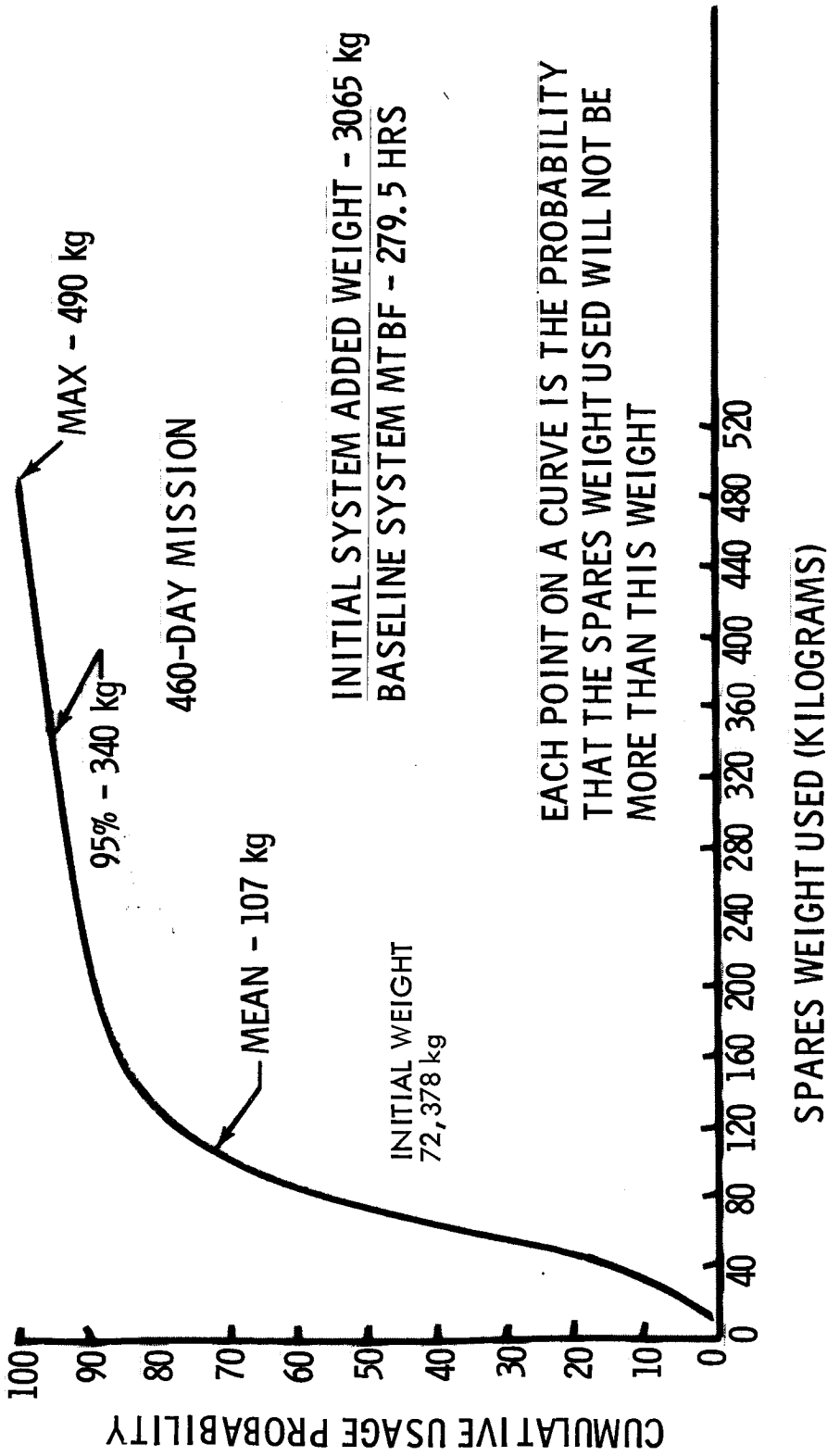


Figure 6.3-13: SPARES WEIGHT USAGE PROBABILITY — 1985 Mars Landing Mission

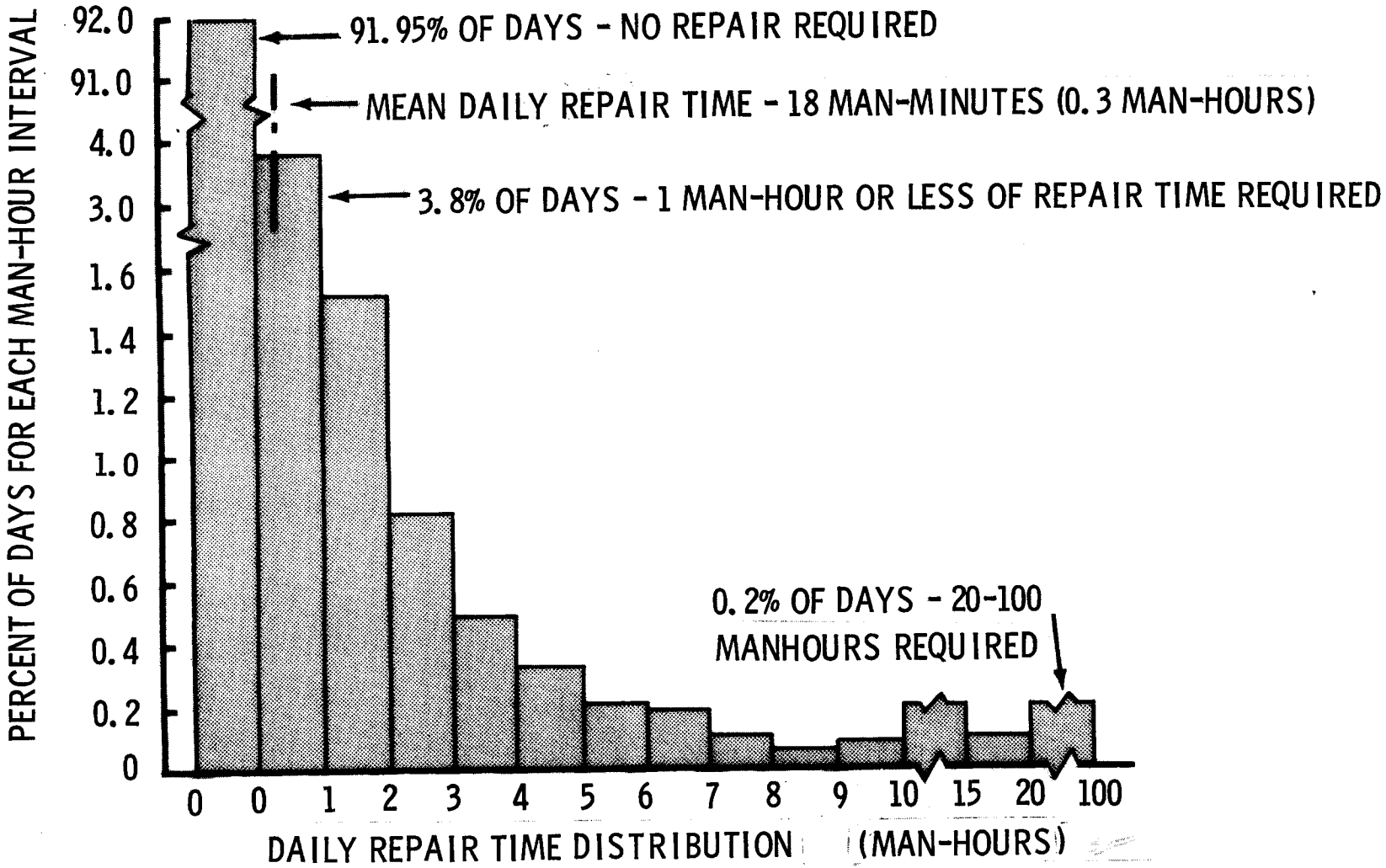


Figure 6.3-14: UNSCHEDULED MAINTENANCE DAILY REPAIR TIME DISTRIBUTION — 1985 Mars Landing Mission

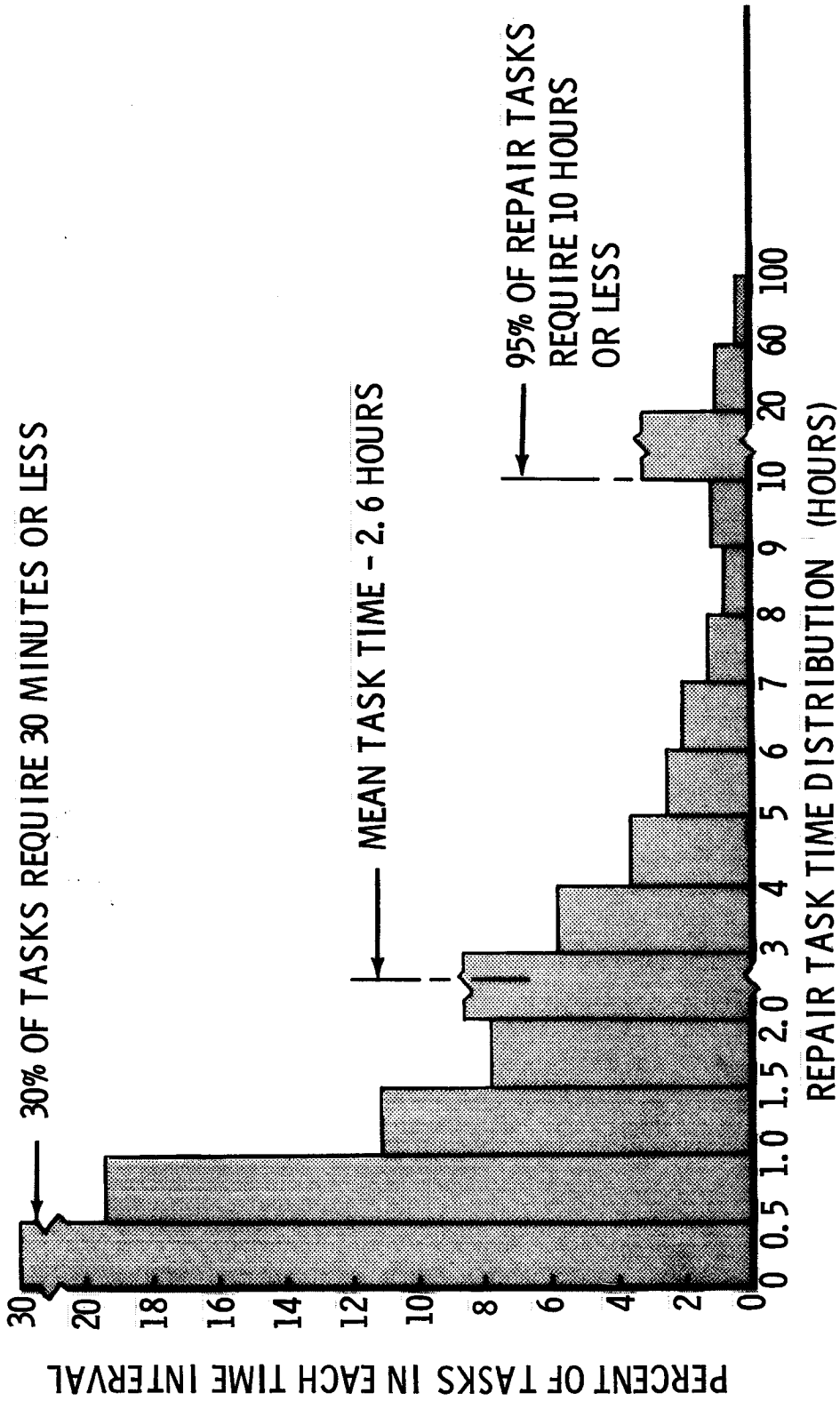


Figure 6.3-15: UNSCHEDULED MAINTENANCE REPAIR TASK TIME DISTRIBUTION — 1985 Mars Landing Mission

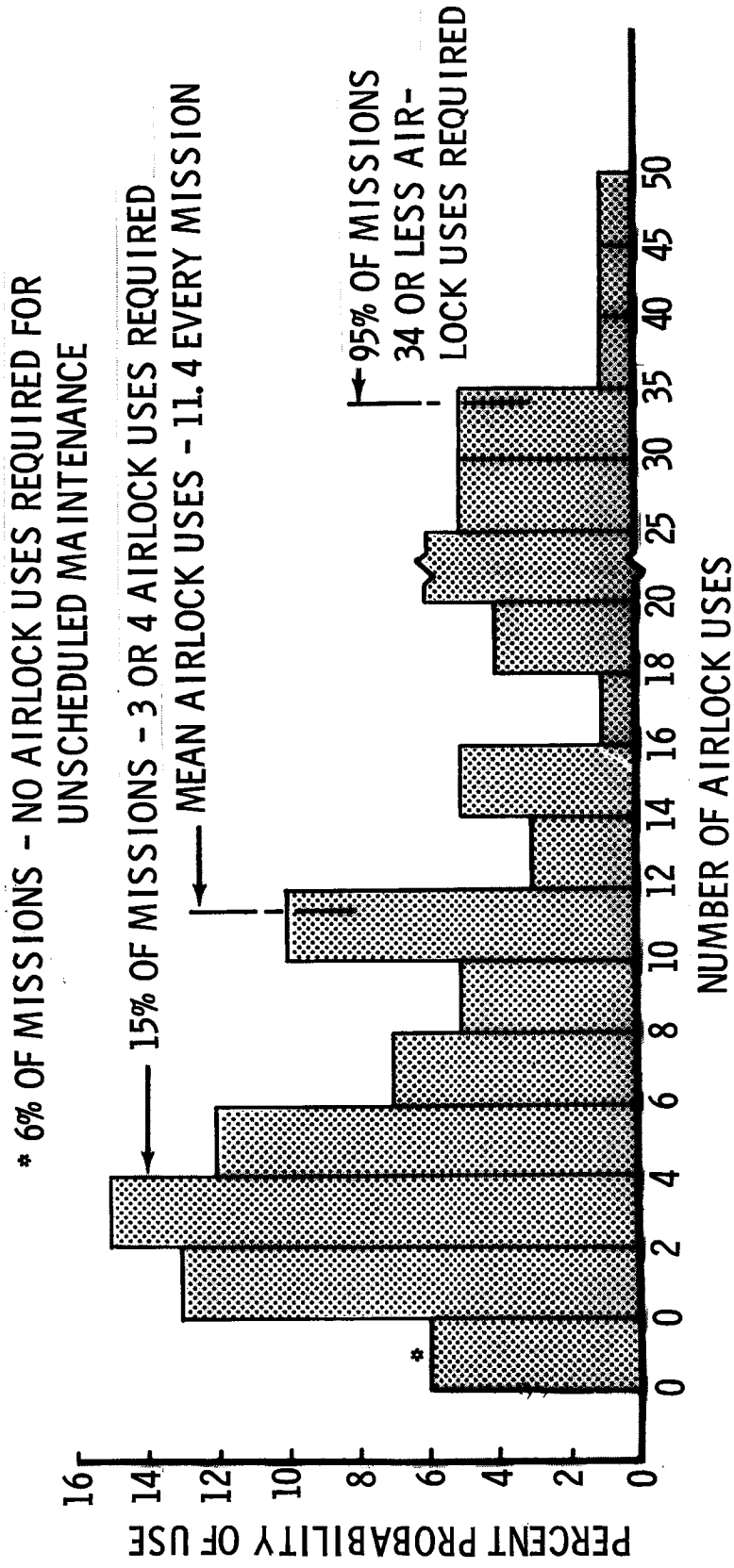


Figure 6.3-16: UNSCHEDULED MAINTENANCE AIRLOCK USAGE DISTRIBUTION — 1985 Mars Landing Mission

for unscheduled maintenance. The mean of the distribution is 11.4 uses per mission, or rounded off so no one gets left outside, 11 uses per mission. Each use is a complete egress-ingress cycle for at least two men. A more meaningful point to look at for planning, is the 95 percentile point. In this distribution the 95 percentile is 34 uses. This means that 95% of all missions will use the airlock 34 or less times for unscheduled maintenance.

Figure 6.3-17 is a companion to Figure 6.3-16 and shows the spacesuit manhours accumulated per mission. The mean here is 60 manhours per mission. The 95 percentile is 192 manhours per mission. If one assumes an equivalent number of hours for experiments and 50 hours for scheduled maintenance inspections, it is found that up to 300 kilograms of suit cooling water can be reclaimed by providing external suit connections at appropriate points. The possibility of suit modification and the weight of plumbing to external connections should be investigated, but it is likely that a net weight savings could be found.

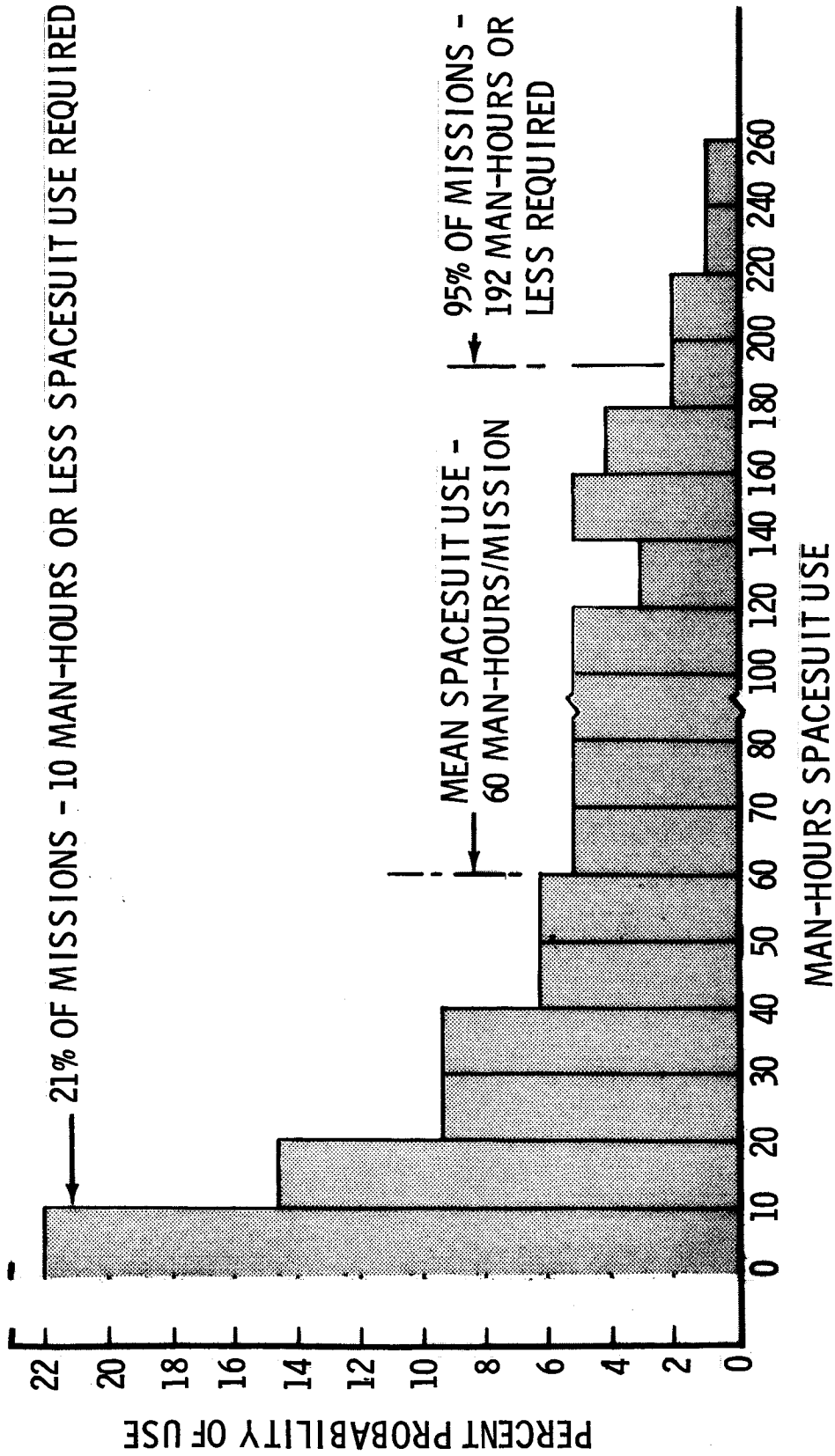


Figure 6.3-17: UNSCHEDULED MAINTENANCE SPACESUIT USAGE DISTRIBUTION — 1985 Mars Landing Mission

# 7.0 GUIDELINES FOR SELECTING SUBSYSTEM MAINTENANCE CONCEPTS

During this study it became apparent that recommendation of an overall or spacecraft-level maintenance concept was difficult because of the exceptions that must be made for individual subsystems. It was decided that recommendation of maintenance concepts at the subsystem level would be more useful. Even at the subsystem level, exceptions to a recommended concept were found, but these could be more easily identified.

Recommendations given here for subsystem maintenance concepts are based on the various analyses and simulations conducted during the study, and upon insights into spacecraft/equipment configuration and operation gained during the structuring of the four mission spacecraft.

## 7.1 GUIDELINES FOR SELECTING SUBSYSTEM MAINTENANCE CONCEPTS FOR EARTH-ORBITAL MISSIONS

A maintenance concept matrix for each of the Earth-orbit missions, the 1975 near-Earth orbital mission and the 1985 $L_1$ Libration Center mission, is presented in Figures 7.1-1 and 7.1-2. Each matrix summarizes the maintenance concepts for the subsystems of the particular mission. Section 3.4.1 defines the "0" through "3" degrees of maintenance categories used in the chart. On the matrices, the recommended concepts are noted by heavy lines and the letter "R." Specific exceptions to the recommended concept are shown under the appropriate degree of maintenance. The notation "FS" indicates a need for further detailed study into the recommended maintenance concept or concepts for a particular system or component. It should also be noted that the maintenance concepts recommended are applicable only for unscheduled maintenance requirements. The maintenance concepts and considerations associated with each of the subsystems for the Earth-orbital missions are discussed in more detail in the following paragraphs.

The subsystems used for the 1985 $L_1$ Libration Center mission are generally the same as for the 1975 near-Earth orbital mission. In many instances, an improvement in reliability was indicated for the 1985 time period because of expected advances in technology by that time. This reliability improvement resulted in a decrease in the expected unscheduled maintenance frequency for the total system from 163 hours MTBF for the 1975 mission to 244 hours MTBF for the 1985 mission. This also resulted in a reduction of the average unscheduled maintenance time per day from 22.5 to 16.2 minutes. Summaries of the relative maintenance workloads of each subsystem are given in Sections 5.2 and 5.3. Modularization for a number of components was also analyzed for the 1985 mission. The results of this analysis are discussed in Section 5.1.

The following sections discuss (1) each of the 1975 subsystems and (2) the differences, as applicable, for the 1985 subsystems.

| MAINTENANCE CONCEPT / SUBSYSTEM | DEGREES OF MAINTENANCE | | | |
|---|---|---|---|---|
| | 0 PARALLEL REDUN | 1 STANDBY REDUN | 2 REMOVE & REPLACE | 3 REPAIR |
| COMMUNICATIONS | RECEIVER/DECODER | R - FOR 90 DAY RESUPPLY IN PARTICULAR FS ↔ | FS INTERCOM TV EQUIP | |
| CREW SUBSYSTEM | | | R | TAPES, BUNKS, BEDDING, EXERCISE EQUIPMENT |
| DATA MANAGEMENT | | | R - WITH MODULARIZATION | |
| ELECTRICAL POWER | SOLAR PANELS, MAIN CONTACTORS | INVERTERS, VOLTAGE REGULATOR | R | WIRING AND CONNECTORS |
| EXPERIMENTS | | | R - MAXIMUM COMMONALITY WITH SPACECRAFT EQUIP. FS ↔ | FS |
| EXTRAVEHICULAR ACTIVITY | | | R FS ↔ | AIRLOCKS, SPACE SUITS, RESTRAINT AIDS FS |
| MAINTENANCE EQUIPMENT | | | R FS ↔ | FS |
| INFLIGHT TEST | | | R | |
| LIFE SUPPORT | | | R | RADIATORS, STORAGE TANKS, PLUMBING, AND DUCTS (FS) |
| NAVIGATION AND GUIDANCE | NOT IDENTIFIED FOR THIS MISSION | | | |
| PROPULSION | RCS ENGINES, SOME PRESSURIZATION EQUIPMENT (FS) | | R - SPARES BACKUP FOR REDUNDANT ITEMS (FS) | (FS) |
| REENTRY | | | R (FS) | STRUCTURE (FS) |
| RENDEZVOUS AND DOCKING | | | R FS ↔ | FS |
| STABILITY CONTROL | CRITICAL ATTITUDE CONTROL ITEMS, REGULATED POWER SUPPLY FS ↔ | FS ↔ | R - SPARES BACKUP FOR REDUNDANT ITEMS (FS) | |
| STRUCTURE | | | PORTS AND WINDOWS FS ↔ | R FS |

R - RECOMMENDED, EXCEPT FOR ITEMS NOTED IN OTHER COLUMNS

FS - FURTHER STUDY OR TRADE INDICATED

**Figure 7.1-1: SUBSYSTEM MAINTENANCE CONCEPT MATRIX — 1975 Near Earth Orbit Mission**

| MAINTENANCE CONCEPT / SUBSYSTEM | DEGREES OF MAINTENANCE | | | |
|---|---|---|---|---|
| | 0 PARALLEL REDUN | 1 STANDBY REDUN | 2 REMOVE & REPLACE | 3 REPAIR |
| COMMUNICATIONS | | R - FOR 180-DAY RESUPPLY, IN PARTICULAR FS | INTERCOM TV EQUIPMT FS | PARABOLIC ANTENNA FS |
| CREW SUBSYSTEM | | | R | TAPES, BUNKS BEDDING, EXERCISE EQUIP, ETC. |
| DATA MANAGEMENT | | | R - WITH MODULARIZATION | |
| ELECTRICAL POWER | SOLAR PANELS, MAIN CONTACTORS | INVERTER, VOLTAGE REGULATOR, BATTERY | R | WIRING AND CONTACTORS |
| EXPERIMENTS | | | R - MAXIMUM COMMONALITY WITH SPACECRAFT EQUIPMT FS | FS |
| EXTRAVEHICULAR ACTIVITY | | | R FS | AIRLOCKS, SPACE SUITS, RESTRAINT AIDS FS |
| MAINTENANCE EQUIPMENT | | | R FS | FS |
| INFLIGHT TEST | | | R - MODULARIZE SOME TEST AND MONITOR EQUIPMT | |
| LIFE SUPPORT | | BOSCH REACTOR | R - SPARES BACKUP FOR BOSCH REACTOR | RADIATORS, STORAGE TANKS, PLUMBING, AND DUCTS (FS) |
| NAVIGATION AND GUIDANCE | INERTIAL PLATFORM (DEGREE 2 MAINT IF MODULARIZED) | | R | |
| PROPULSION | RCS ENGINES, TANKS SOME PRESSURIZATION EQUIPMT | | R - SPARES BACKUP FOR REDUNDANT ITEMS (FS) | (FS) |
| REENTRY | | | R (FS) | STRUCTURE (FS) |
| RENDEZVOUS AND DOCKING | | | R - MODULARIZE TRANSPONDER | |
| STABILITY CONTROL | SUN-SEEKER, HORIZON SCANNER, REGULATED POWER SUPPLY FS | CONSIDER FOR SOME OF ELECTRONICS EQUIPMT | R-SPARES BACKUP FOR REDUNDANT ITEMS FS | |
| STRUCTURE | | | PORTS, WINDOWS FS | R FS |

R - RECOMMENDED, EXCEPT FOR ITEMS NOTED IN OTHER COLUMNS FS - FURTHER STUDY OR TRADE INDICATED

Figure 7.1-2: SUBSYSTEM MAINTENANCE CONCEPT MATRIX — 1985 $L_1$ Libration Center Mission

### 7.1.1 COMMUNICATIONS SUBSYSTEM

Degree "1" maintenance (standby redundancy) is generally recommended for the 90-day resupply 1975 mission and 1985 180-day resupply because of the low spares required to achieve the required reliability. Exceptions were for the intercom and TV equipment which it would not be practical to make redundant. For the 1985 mission it is recommended that a repair capability be provided for the parabolic antenna. Also, for longer mission times, Degree "2" maintenance becomes more practical than Degree "1."

All components of this system, except for the antennas, are located within pressurized areas of the spacecraft which are occupied by the crew. Access to the components will generally be good and replacement can be accomplished in a shirtsleeve environment. Replacement or maintenance of the antennas will require EVA, and therefore must be accomplished within the constraints of a pressurized spacesuit and backpack (PLSS). However, with the low failure rate of the antennas, it is expected there will be no more than one, and probably not any, random antenna failure during a 5-year mission. Because of the hazard presented, there is some possibility of damaging an antenna during EVA or docking operations with a logistics vehicle, but again, an antenna failure from these causes is expected to be slight. The expected unscheduled maintenance frequency for the 1975 baseline communications system is 2132 hours (89 days). The components expected to require the most unscheduled maintenance are the intercom control panels; there is a 75% probability that one will have to be replaced during any one 90-day period. Therefore, this item should be designed for easy replacement or repair.

It appears that two of the heavier components, the multiplexer and the digital command receiver/decoder, could be modularized, resulting in a reduction of the initial spares weight. However, the computer program indicated only one of each was required for a 99% probability of mission success. Therefore, modularizing these components may not be justified. There was no scheduled maintenance required for the communications system.

The inclusion of a 10-foot parabolic steerable antenna in the 1985 system is the only change that will affect maintenance of this system. Any malfunctions of the pointing mechanism or motors will require EVA to replace the faulty item. Therefore, design of equipment must take this into consideration. There may also be a requirement to lubricate the pointing mechanisms, but this should be avoided if possible. The MARCEP analysis indicated there would be a requirement for a spare antenna, in order to achieve 99% probability of mission success.

The spare antenna may present some storage problems unless it is designed to be collapsible, or can be stored in a disassembled condition and then easily reassembled if needed. Another alternative is to omit such a spare initially, but to include one in a resupply mission if the requirement arose. However, it is believed maintenance of the antenna could best be done by providing a repair capability. Therefore, it was recommended that the antenna be designed for repair. If a total loss of transmission or receiving capability occurred which could not be repaired with the maintenance equipment provided, communications

could still be maintained by using the reentry system command module equipment. This would result in some degradation of capability but it might be tolerated until the next resupply mission. This antenna will also present some hazard to personnel while they are working outside the spacecraft. Possible mechanical or shadowing interference between the antenna and solar panels must also be considered in the system design.

The expected unscheduled maintenance frequency for the 1985 system is 4936 hours (205 days). The components causing the most failures are the intercom control panel and the TV camera, which have a 38% and 32% probability, respectively, of failing during any one 180-day resupply interval.

### 7.1.2 CREW SYSTEM

Degree "2" maintenance (remove and replace) is recommended for this system except for some items which are more practical to repair as noted in the matrices.

All of the equipment considered as part of this system is located within pressurized areas occupied by the crew, and access to the equipment will be good. Disposable garments are used to eliminate the need for washing and drying equipment, and to decrease the workload of the crew. Film viewing equipment is included with the crew system for recreational microfilm reading material. However, it appears this function could be incorporated in the file unit console viewer of the data management system. The expected unscheduled maintenance frequency for the 1975 crew system is 50,000 hours (2080 days).

Scheduled maintenance attributed to the crew system includes general interior cleaning of the spacecraft; inspection and/or cleaning of vacuum cleaners, fire extinguishers, and film projectors; and replacement of some lamps. Because of limited life, it is expected that an average of two fluorescent and one incandescent lamp will have to be replaced every 90 days. The crew system scheduled maintenance amounts to about 53 man-minutes per day. Most of this time results from the general interior cleaning function which has been listed as a weekly requirement. It may very well be that future space flights will indicate this task is not necessary, or with proper operational procedures can be performed at less frequent intervals. Any improvement in this area will significantly reduce the scheduled maintenance workload. An additional 60 man-minutes will be required at resupply intervals for replenishment of crew clothing and personal items.

There is no significant change in the 1985 system except for increasing some facilities to support the 12-man crew. The expected unscheduled maintenance frequency is 48,850 hours (5.6 years).

### 7.1.3 DATA MANAGEMENT SUBSYSTEM

Degree "2" maintenance (remove and replace) is recommended for all of this system with the added recommendation that the electronic equipment be modularized as much as possible. All components of this system are located in pressurized areas occupied by the crew, and access to the equipment will be good.

The computer and data adapter are relatively heavy items with high failure rates, and therefore a number of spares are required to ensure a 99% probability of successful operation throughout the mission. Modularization of these items resulted in a considerable savings in initial spares weight requirements as explained in Section 5.1. Therefore, it is highly recommended that the computer and data adapter be designed to permit ready identification of failures to a module level and easy replacement of the module.

The typewriter is a fairly complex device that requires thorough training in its repair. If this maintenance capability exists, then parts of typewriters could be spared, instead of complete typewriters, with a resulting savings in spares weight. However, it is believed the savings in weight cannot be justified by the added crew training costs. The MARCEP analysis indicated three spare typewriters would be required for 99% probability of mission success for 180 days. However, since mission success will not be seriously curtailed by temporary loss of this function, it is recommended that only one spare be carried on board. Additional spares can be brought up as required on the resupply vehicles. The expected unscheduled maintenance frequency for the 1975 data management system is 2500 hours (108 days). The component expected to fail most frequently is the data adapter; there is a 59% probability of failure during any one 90-day period, based on the simulation program results. Modularization will decrease the maintenance time of this item also.

Scheduled maintenance on this system consists of inspecting and cleaning the typewriter, console viewer, and film projection/scanner unit, and replacing projection lamps. This scheduled maintenance averages out to just over 1 man-minute per day.

There is no significant change in the 1985 system except for a considerable improvement in reliability and capability. The expected unscheduled maintenance frequency is 7867 hours (328 days).

### 7.1.4 ELECTRICAL POWER SUBSYSTEM

Degree "2" maintenance is recommended for this system except for the items noted in the matrices. All components of this system, except for the solar panels, are located in the pressurized storage compartment located between the crew living area and the operational area. Access doors are provided to facilitate maintenance of this equipment. Interconnecting wiring that could possibly require repair or modification will be connected using wire-wrap techniques for high reliability and easily repairable connections. These techniques will preclude the need for wire soldering equipment and its associated problems.

It is assumed that there will be no capability of repairing the solar panels while in orbit. Therefore, the solar panels must be designed initially to provide the required power for a 5-year period assuming expected degradation. The solar panels will present some hazard to crew members working outside the spacecraft and to logistics vehicles during docking operations. If extensive damage does occur, the situation will have to be evaluated to determine:

a) whether operations can be continued until a logistics vehicle can bring the necessary equipment to accomplish a repair;

b) if repair cannot be accomplished, then possibly operation at a reduced power level will be required, perhaps with a smaller crew, to continue the mission; or

c) if the spacecraft must be abandoned and the crew returned to Earth.

In any case, it is apparent that adequate procedures for docking operations and movement of extravehicular crew members must be devised to preclude the possibility of solar panel damage.

The computer analysis indicated that some redundancy of the main electrical power contactors, inverters, and voltage regulators would be required to ensure continuous availability of electrical power. The anticipated battery life is 1 year. Therefore, scheduled replacement of all six batteries will be required each year, and one inverter will require replacement every 2 years. The 1975 electrical power system scheduled maintenance amounts to 1550 man-minutes (25.8 manhours) per year. An improvement in the battery state of the art to increase the service life is required to substantially reduce the scheduled replacement workload. Also, because of the existing scheduled replacement requirements, it is necessary that good access be provided for replacing the batteries. Procedures must be established for isolating the battery to be replaced and for distributing the power demands over the remaining batteries.

Unscheduled maintenance of batteries between scheduled replacements will consist of replacing defective battery cells. It is necessary to replace failed cells promptly as they can cause gassing, excessive pressure buildup, and possible cell rupture. Replacement of a cell will result in isolating the battery from the power system for about 24 hours. Initially, 10 to 15 hours are required to allow internal pressures to dissipate, and then conditioning of the battery will be required to ensure that the old and new cells are in a similar state of charge. However, the demands on crew time are expected to be only about 2.5 manhours.

The expected unscheduled maintenance frequency for the 1975 electrical power system is 11,848 hours (494 days). The battery charge regulators, fuse and circuit breakers, and module interconnecting wiring failed the most frequently in the mission simulation program, but even then the probability of a failure during a 90-day period was only 3% for each of these components.

The only significant changes in this system for the 1985 mission are a slight decrease in solar panel area and a decrease in batteries from 6 to 1. The battery life was also increased to 2 years which will considerably reduce the scheduled maintenance requirements of this system. Since only one battery is in the basic system, and its operating cycle is not as severe as for 1975, battery cell replacement was not considered. The MARCEP analysis indicated one spare battery would be required to achieve a 99% probability of mission success over a 180-day resupply period. It is thought in this case that the spare should actually be wired into the power system. Then, if the basic battery fails, the other would be adequate to provide operational requirements until

the next resupply, at which time a replacement could be brought up. The expected unscheduled maintenance frequency is 20,000 hours (2.3 years). The items that failed most in the simulation were fuses and circuit breakers, which had an 8% probability of failure during any one 180-day interval.

### 7.1.5 EXPERIMENT SYSTEM

Degree "2" maintenance is recommended for this system. A detailed maintenance analysis of the experiment packages is beyond the scope of this study. Further detailed study will be required to define specific maintenance requirements of experiments. In fact, the maintenance of equipment used in experiments may actually be considered as part of the experiment itself. Therefore, experiments were identified as gross packages of a typical weight and volume as indicated in the MARCEP data sheets. In the initial design of experiment packages, it is strongly recommended that wherever possible the equipment used be common with spacecraft subsystem equipment and components. Commonality in this area would provide an additional source of spares, allow more effective use of existing spares, and most likely could result in a reduction of total spares requirements. The maintenance developed for this system in the study is mainly that required to support the experiment airlock, mounting masts, and mounting booms. Extravehicular activity will be required to replace most components of this equipment. However, the anticipated failures are quite low, as indicated by an expected unscheduled maintenance frequency of 34,130 hours (4.0 years) for the 1975 system.

The only scheduled maintenance identified was a requirement for lubrication of some experiment equipment mechanisms, which required 30 man-minutes every 90 days.

The only significant change for the 1985 system is an increase in the number of experiments because of the 12-man crew. This resulted in a slightly lower expected unscheduled maintenance frequency of 22,589 hours (2.6 years).

### 7.1.6 EXTRAVEHICULAR ACTIVITY EQUIPMENT

Degree "2" maintenance is also recommended for this system except for the airlock, spacesuits, and restraint aid equipment where it was thought repair would be more practical. The equipment making up this system will be stored or located inside the vehicle except for some powered and manual locomotion items. Maintenance of the airlock may require working in a pressurized spacesuit depending on what malfunction occurred. Very little information was available on the Litton hard suit for this study. However, it is expected that some suit repair may be accomplished by sewing, patching, or replacement of disconnect or joint seals. It is also expected that some maintenance of the backpack may be performed. Further study is required to determine detailed maintenance requirements of the spacesuit and backpack. Since sufficient data was not available to make a detailed analysis of the above items, and also of the powered locomotion devices, repair of these items was assumed to require a special maintenance kit of an estimated average weight and volume. However, the use rate of this equipment should be quite low and therefore should not generate many failures. The expected unscheduled maintenance frequency for the 1975 system is

24,570 hours (1023 days). The limited maintenance that was required was mainly attributed to the spacesuit and the remote maneuvering unit. The simulation showed a 5% probability of a spacesuit failure and a 3% probability of an RMU failure during any one 90-day period.

There is some scheduled maintenance of the backpack and spacesuit required before and after every use, such as checkout and servicing. The time required to accomplish these functions is assumed to be included in the 30 minutes allowed in the tasks requiring EVA for egress and ingress of the vehicle. See assumptions included in Section 3.2.

The changes in this system for 1985 amounted to increasing the spacesuit and backpack requirements to support 12 men and showing an improvement in reliability of these and the powered locomotion devices. The expected unscheduled maintenance frequency is 41,649 hours (4.3 years).

### 7.1.7 INFLIGHT MAINTENANCE EQUIPMENT

Degree "2" maintenance is recommended for this system as it was not considered practical to make this equipment redundant. Further study is required to determine the feasibility of repairing this equipment. All components of this system will be located at the maintenance station. These items are to be used in the performance of maintenance in conjunction with the inflight test system. The unscheduled maintenance caused by this equipment will be minimal as evidenced by the expected unscheduled maintenance frequency of 178,571 hours (20 years) for the 1975 mission.

The 1985 system is the same as for the 1975 mission. Some improvement was shown in the reliability of the electron-beam welder, and the usage rate of this item was increased which resulted in an increase in failures. The expected unscheduled maintenance frequency is 16,700 hours (2 years).

### 7.1.8 INFLIGHT TEST SUBSYSTEM

Degree "2" maintenance is recommended for this system as excessive redundancy would be required for Degree "0" or "1." See Section I.7 of the appendix for further discussion. All components associated with this system are at one of the operations or maintenance stations. Most of the switches, lights, meters, and other displays will be mounted on panels. Because of the profuse numbers of these items, some of which have a relatively high failure rate, the maintenance will be relatively high. Therefore, it is necessary that all of this equipment be mounted for easy disconnection and removal from the system. Many of the components are small in size and some design thought will be required to provide sufficient access so the items can be handled without escaping. All screws and nuts used for mounting these items should be captive to prevent their loss. In addition, it may be necessary to devise a method of retaining control of the item being removed, such as small tethers using an adhesive material, fine-mesh nets, etc. The expected unscheduled maintenance frequency for the 1975 inflight test system is 890 hours (37 days). The components that failed most frequently were digital readout indicators (82%), digital time indicators (47%), and the flight director display (35%). The percent values reflect the

probability of the component failing during any one 90-day period. The scheduled maintenance attributable to this system is a daily function of reading the console displays and recording readings as required.

The system is basically the same for 1985 except for some reliability improvements. The expected unscheduled maintenance frequency is 996 hours (42 days).

### 7.1.9 LIFE SUPPORT SUBSYSTEM

Degree "2" maintenance is recommended for this system as it is impractical to incorporate the redundancy that would be required. Repair was recommended for the space radiator, large storage tanks, and plumbing and ducts. However, further study is required into the repair possibility.

Components of this system are located throughout all pressurized sections of the spacecraft. The space radiator is integral with the exterior structure and EVA will be required for maintenance of this item. However, the expected failure rate of the radiator is very low and the simulation did not show any failures during the 100 simulations. If a radiator failure should occur, it is expected to involve leakage from a punctured radiator tube. Redundant radiator tubes are included so one leak will not result in complete loss of thermal radiation capability. Repair would be accomplished with some type of fusion joining equipment to patch a puncture.

The expected unscheduled maintenance frequency for the 1975 life support system is 354 hours (15 days). The components of the system expected to cause the most unscheduled maintenance are atmospheric supply pressure switches (54%), water heating indicator lamps (49%), gas pressure regulator valve (44%), and rotary fluid bypass valve (40%). The percentage figures indicate the probability of the item failing during any one 90-day period.

The scheduled maintenance requirements for the life support system comprise the majority of the spacecraft scheduled requirements as shown in Section 5.2. Since the scheduled maintenance is the major maintenance workload imposed on the crew, the greatest benefit to be gained will be from decreasing the scheduled maintenance workload. Where scheduled maintenance cannot be eliminated or the frequency decreased, it is necessary to design the system so the maintenance can be very readily accomplished.

The 1985 system is basically the same as for the 1975 mission. Improvements in reliability have been shown where considered feasible and the frequency of scheduled maintenance has been decreased. However, this system still requires an average of over 30 minutes per day for scheduled maintenance. This indicates there still are benefits to be gained from reducing scheduled requirements by redesigning features, such as carbon disposal, that now require crew attention. The expected unscheduled maintenance frequency is 600 hours (25 days).

### 7.1.10 NAVIGATION AND GUIDANCE SUBSYSTEM

Degree "2" maintenance is recommended for this system except for the inertial platform which required parallel redundancy. However, if this item were properly modularized, it is believed Degree "2" maintenance would apply to it as well.

This system was identified only for the 1985 mission. All components have been assumed to be replaceable from within the pressurized spacecraft. This will require a design for installation of the space sextant and scanning telescope with a separate window through the pressure hull to provide the desired field of view. Again, since the windows might have to be replaced they should be in a double configuration, as mentioned in the structure subsystem discussion. It may require some design advance to provide a window installation with the required optical qualities. Another possibility would be to use a single window configuration with a protective cover which could be controlled remotely as required.

The MARCEP analysis indicated a requirement for a parallel redundant inertial platform to achieve the desired 99% probability of mission success. If the mean replacement time of 4 hours could be decreased, or the allowable downtime of 12 hours increased, the required probability could most likely be met with a standby redundant or spare unit. The expected unscheduled maintenance frequency for this system is 16,502 hours (1.9 years).

### 7.1.11 PROPULSION SUBSYSTEM

Degree"2" maintenance is generally recommended for this system. However, since EVA is required to perform maintenance on this system, some redundancy of critical items was assumed. Further study is required on this system to determine the most practical maintenance concepts for the different components.

All components of this system are located in the unpressurized interstage area of the spacecraft. Therefore EVA will be required for all maintenance and the system must be designed to facilitate replacement of components within the system while working in a pressurized spacesuit. The engines which require scheduled replacement on a yearly basis must be designed for easy disconnection from propellant and electrical lines, and for removal and replacement. Any propellant lines that are opened during maintenance will require purging with nitrogen. Therefore, the nitrogen pressurant should be interconnected with the propellant lines with the valving necessary to permit the purging to be done. Procedures must also be established to preclude the firing of the reaction-control engines while crew members are outside the spacecraft, and in particular while working on the propulsion system. The simulation model did not show any failures of propellant tanks during the 100 simulations and only one spare tank assembly was initially required to ensure the 99% probability of mission success. Therefore, leakage of a tank itself is not expected to occur during a 5-year mission. However, procedures must be provided to cope with the problem in the event it does occur. If the leak is minor and not an immediate hazard, it may be possible to use this tank to feed all engines and thereby deplete its supply faster. Or, it may be possible to depressurize the tank, apply a temporary

patch, then repressurize only as required to use up the propellant. Even if the propellant supply of one tank is lost, there is presumed to be sufficient reserve capacity in the system to allow normal operation until the next resupply. Valves are provided in the system to isolate any replaceable component.

The expected unscheduled maintenance frequency for the 1975 propulsion system is 6662 hours (276 days). The most frequent failures occurred with the solenoid purge valve and the solenoid engine prevalve, which had probabilities of 8% and 7%, respectively, of failing during any one 90-day interval.

The scheduled maintenance requirements, other than resupply functions, involve the annual replacement of the reaction-control engines, which causes a major workload on the crew. Therefore, this is another area where a significant reduction in scheduled maintenance time could be obtained by increasing the expected engine life and simplifying the replacement procedure. A considerable improvement in the design life of engines must be shown to achieve this goal.

The 1985 system is basically the same as for 1975, except some of the components are repackaged into assemblies to facilitate that maintenance requiring EVA. Instead of assuming replacement of individual attitude control engines during both scheduled and unscheduled maintenance, it was assumed these engines would be packaged into assemblies of three engines each. The larger package should be easier to design for ready replacement also. With an increase in the time between scheduled replacements and a reduction in the number of items to be replaced, the workload will decrease significantly.

The components comprising the nitrogen high and low pressure modules and the propellant transfer module were assumed to be replaced individually whenever a failure occurred in the 1975 mission. For 1985 it was assumed these modules would be replaced as an entire unit. This again will make it easier for the designer to provide a readily replaceable installation. These three modules require replacement more frequently than any other in the system. The probability of failure of any one of these modules during a 180-day period is: high pressure module---14%, low pressure module---52%, and transfer module---28%.

With this concept of replacing complete assemblies when EVA is required, the removed assemblies could be returned to the maintenance test station where Degree "3" maintenance could be performed in a shirtsleeve environment. The economics of doing this, however, would depend on the number of failures involved. Removed modules should be enclosed in a propellant-resistant bag to prevent release of residual fuel within the spacecraft. A vacuum system could be used to clean out the item before and during maintenance. This concept did result in some increase in the expected failure frequency of the system, which for the 1985 system is 4666 hours (194 days).

### 7.1.12 REENTRY SYSTEM

Except for structure which was assumed to require repair (Degree "3"), Degree "2" maintenance is recommended.

The Apollo command module and service pack which comprise the reentry system are stowed on the exterior of the spacecraft. While in orbital storage, the reentry system will have no major equipment operating. Thirty and 90-day checks of the stowed spacecraft will be conducted. The 90-day checkout will be the more extensive and will be conducted just prior to a resupply mission so additional equipment can be requested if needed. Since it was not practical to go into the kind of detailed analysis on the Apollo subsystems that was performed on the basic spacecraft systems, a maintenance kit of a weight and volume estimated to be required for an average reentry system repair was postulated. Depending on the location of the malfunction, EVA may or may not be required. If the reentry system is in one of the stowed positions, EVA will be required to gain access to the system. If the reentry system is rotated to the docked position, then the interior of the vehicle is accessible without EVA. Because of the low operating time while stowed, the expected unscheduled maintenance frequency for the 1975 system was quite low---21,400 hours (about 2-1/2 years). Maximum commonality of reentry systems and spacecraft systems should be achieved, particularly for electronic equipment.

The same Apollo command module is used for the 1985 mission, but a service module is required instead of the service pack. Also, two reentry systems are required to provide abort capability for 12 men. The stowage arrangement is such that access to the inside of the command modules is provided directly from the mission spacecraft. EVA will still be required for components not within the pressurized part of the command module. The expected unscheduled maintenance frequency is 21,470 hours (2.5 years).

### 7.1.13 RENDEZVOUS AND DOCKING SUBSYSTEM

Degree "2" maintenance is recommended for this system, but further study should be made into details of the system to determine if repair of some items might not be more practical.

Maintenance of the rendezvous and docking system will require EVA for all components except the rendezvous radar transponder and interrogator. The failure rates of the mechanical components are relatively low and the operating time is low; therefore few failures of these items are expected to occur. The expected unscheduled maintenance frequency for the 1975 system is 7189 hours (300 days); the majority of failures are attributable to the radar transponder and interrogator. These two components have a 14% and 13% probability, respectively, of failing during any one 90-day interval. Therefore, these components should be readily accessible and replaceable. The possibility of modularizing these items to reduce the spares weight carried on board and to decrease the maintenance time should be considered.

The only scheduled maintenance identified for this system was a 90-day inspection and lubrication of mechanical linkages which will require EVA. This function should be accomplished just before each resupply launch to ensure it is operating correctly. It would be best to design the system so no lubrication will be required, but when lubrication is required, particular attention should be directed to permitting sufficient access to accomplish the task while in a pressurized spacesuit. Before specifying a requirement for lubrication of any

item, cognizance must be taken of the special problems created by the zero-g space environment. This is an area that will require investigation on future space flights and should be included as part of an experiment program.

For 1985, this system was changed to a simpler and more reliable docking system, and the radar interrogator was deleted, which further increased the system reliability. EVA still is required for maintenance of most of this system. The expected unscheduled maintenance frequency is 15,768 hours (1.8 years).

### 7.1.14 STABILITY AND CONTROL SUBSYSTEM

Degree "2" maintenance is generally the best for this system, except that parallel redundancy is required for components that are critical to attitude control of the spacecraft.

The system consists mostly of electronic components, a number of which have relatively high failure rates. All of the components are accessible from within the spacecraft, except for the two-axis narrow-angle sun seeker and the two-axis horizon scanner. These two sensors are located on the exterior surface of the spacecraft and will require EVA; however, these items have a low operating time and will not be subject to very frequent failure. For easy replacement, they should be mounted inside the spacecraft with a window to provide the desired field of view. Since the horizon scanner is an infrared device, a germanium window would be necessary. The control-moment gyros (CMG's) are heavy, bulky components which, if replacement were required, very often could create a spares storage problem. To facilitate maintenance of the CMG's, the rotor and torquer bearing assemblies are each contained in a replaceable cartridge with a pre-adjusted, prelubricated, matched-bearing assembly. Separating these components out resulted in a sufficiently low failure rate such that only one spare of each type CMG was required to achieve the desired 99% probability of mission success. No CMG spares are required for a 99% probability of crew survival. Since the simulation program indicated only a 2 to 3% probability of a spare CMG being required during any one resupply interval, it is suggested that no spare CMG initially be provided on board. This will reduce the initial spares weight by about 112 kg and reduce the storage requirements by a little over 0.5 cubic meter (18.5 cu ft). If a CMG malfunction should occur that cannot be corrected by replacing a bearing assembly, there should be capability remaining in the momentum storage system and reaction control propellant to operate satisfactorily until the next resupply. At this time, a replacement CMG could be brought up to the spacecraft.

The expected unscheduled maintenance frequency for the 1975 system is 1074 hours (45 days). The most frequent failures were caused by the rate gyros (27%), desaturation logic electronics (31%), and valve drive electronics (31%). The percent values indicate the probability that one of these components will fail during any one 90-day interval. There was no scheduled maintenance identified for the stability and control system.

The 1985 system is basically the same as for the 1975 near-Earth orbital mission except for the deletion of two CMG's and the inertial platform; the

latter is now included as part of the navigation and guidance subsystem. Some reliability improvement has been indicated for a number of the components. The maintenance concept will still be the same as for the 1975 mission. The expected unscheduled maintenance frequency is 2277 hours (95 days). The probability of failure during any one 180-day period for the components which failed most frequently were: desaturation logic electronics---24%, valve drive electronics---63%, CMG sync and control electronics---23%.

### 7.1.15 STRUCTURE SUBSYSTEM

Degree "3" maintenance (repair) is the most practical for structural items. The only exceptions noted were ports and windows which would be replaced (Degree "2").

Maintenance of this system will involve EVA whenever a failure concerns external structure. The spacecraft structure is designed to better than 99% probability of withstanding micrometeoroid impacts during the mission. Therefore, maintenance of exterior structure will more likely be the result of damage caused by inadvertent collision during EVA or docking operations. Punctures might be sealed through the use of adhesive patches, metal or plastic plugs, or patches secured by electron-beam welding or other types of fusion joining process. Although repair of exterior structure or the pressurized hull is expected to be infrequent, the structure still should be designed so that punctures can be repaired from within the spacecraft whenever possible. Some thought must also be given to means for detecting and locating pressure leaks. (This is covered in more detail in Section 10.1.) Most damage is expected to be slight enough that if the condition warrants it, the crew will have ample time to don their spacesuits. Maintenance of interior structures will generally consist of repairing inadvertent damage caused during equipment handling, personnel movements, etc. Repairs will be accomplished using a basic metal or fabric repair kit.

The expected unscheduled maintenance frequency for the 1975 structure system is 625,000 hours (about 72 years) and therefore is not anticipated to be a major problem.

The only scheduled maintenance identified is an inspection of the spacecraft exterior every 30 days. It may be possible to increase the interval between these inspections as more experience is gained on manned space flights and adequate provisions are designed into the structure for automatically detecting damage to exterior structures. Another aspect to consider is the gradual deterioration of visibility through any windows from numerous micrometeoroid impacts or erosion from solar dust. This may require periodic replacement of windows. It will be important that window design allow for easy replacement. One possible design is a double window configuration in which the inner window takes all pressure loads and the outer window is easily replaceable and used to protect the inner window. In this case, outer window replacement would not require spacecraft depressurization, and the only crew members that would need to put on spacesuits are those that will perform EVA to accomplish the replacement.

The 1985 system is the same as for 1975 except for some weight increases and the requirement for a considerable amount of radiation shielding. The probability of failure (defined as the requirement to repair the pressure shell, e.g., a micrometeoroid puncture) is the same as for the 1975 mission, and is estimated to be only 7% for a flight of 5 years duration.

## 7.2 GUIDELINES FOR SELECTING SUBSYSTEM MAINTENANCE CONCEPTS FOR INTERPLANETARY MISSIONS

Figures 7.2-1 and 7.2-2 summarize, in matrix form, subsystem maintenance concept recommendations for the 1975- and 1985-period planetary-class missions. Recommended concepts are identified by degree of maintenance. Degrees of maintenance are discussed and defined in detail in Section 3.4.1. Maintenance activity increases as the degree increases, Degree "0" indicating a maximum of redundancy and automated maintenance, and Degree "3" indicating a maximum of manual repair, including piece part repair. Detailed discussions by subsystem follow in Sections 7.2.1 through 7.2.16. In Figures 7.2-1 and 7.2-2, recommended concepts are indicated by heavy outlines and "R." Specific exceptions to the recommended concept are indicated under appropriate degrees of maintenance for each subsystem. The need for further study into the degree of maintenance recommended for a component or among different maintenance concepts is indicated by "FS." It should be remembered that the maintenance concepts recommended apply only to the requirement for unscheduled maintenance.

### 7.2.1 COMMUNICATIONS SUBSYSTEM

Degree "1" maintenance is recommended, with minor exceptions, for the 1975 interplanetary mission. This recommendation is made with the understanding that the trade between Degree "1" and Degree "2" is so close that further study is necessary; the recommendation is intended primarily to reduce maintenance workload. Under the Degree "2" concept, the subsystem becomes one of the major contributors to unscheduled maintenance workload. Even under Degree "1," it will contribute to the workload because of the exceptions that are noted.

Most of the components in the communications subsystem were augmented with relatively small numbers of spares (1, 2, or 3). These items could be designed as built-in spares (standby redundancy) without major weight penalty or design problems. This might also be true for the antenna system, but repair of the antenna seems more practical. Antenna repair was recommended as an exception to the general Degree "1" concept, but further study is also required. The 500-watt transmitter amplifier and possibly the transmitter power supply are also exceptions. The transmitter amplifier was added as a spare 6 times, and it seems impractical to design and install 6 standby transmitters. One level of standby backed up by spares seems a practical way to go. The power supply was added five times as a spare, and further study seems necessary to determine if spares are preferable to built-in redundancy. Intercom control panels (of which there are nine basic) were augmented by eight spares. Spare control panels are recommended because of the wall space consumed and the complex switchover capability required to make the control boxes standby redundant. Wiring and interconnections should be made repairable or replaceable where possible.

For the 1985 communications subsystem, Degree "2" maintenance is recommended. The primary means of data transmission to Earth for the 1985 mission will be by laser, and some of the laser equipment poses a problem that requires Degree "2" maintenance. The laser assembly has a low use life, about 2000 hours, which makes scheduled maintenance mandatory. Because the laser assembly must be designed for easy replacement, it is very likely that other associated components can be made replaceable without much difficulty. Further, the telescope and optical equipment used to control the laser beam are very bulky (but not too heavy) and would consume a large volume if they were spared or made redundant as complete assemblies. It seems necessary to design the optics (mirrors) to be replaceable, and the supporting tube to be repairable. Most other elements of the communications subsystem were found to require minimum numbers of spares and presented no problem to design of redundancy. Therefore, all other components are recommended for Degree "1" maintenance. Further study into this concept is recommended because the number of repair actions is expected to be so low that allowing some repair activity may be desirable for crew morale and stimulation.

### 7.2.2 CREW SUBSYSTEM

Degree "2" maintenance is recommended for the crew subsystem in both the 1975 and 1985 time periods. There is naturally a very high degree of similarity between the crew systems for the two time periods, and significant weight and reliability improvements are not foreseen. The major portion of the crew system is equipment that has achieved its reliability and weight improvements already. Indicative of this point is the expected unscheduled repair time for the 1975 mission which was found to be 70 minutes on the average and expected to occur about once every 3400 days. Most of the components in the crew system can easily be replaced, upon failure, with a spare, and redundant design of many poses a logic problem. For example, how does one design a redundant dental care kit? Other items such as lighting must be designed for scheduled maintenance, and sparing becomes a natural choice of repair mode. Overdesign to a point where no failures can reasonably be expected is possible in some cases, but the additional cost appears to be unnecessary.

There are a few exceptions to the recommendation of Degree "2" maintenance. These include such items as bunks and TV tapes, which probably should be repaired. The TV tapes, which are provided for recreation and leisure use, should be repaired with a splicing kit or eliminated from any maintenance consideration at all. These items were tentatively identified as Degree "3" maintenance exceptions to the general Degree "2" recommendation.

### 7.2.3 DATA MANAGEMENT SUBSYSTEM

In general, Degree "2" maintenance is recommended for the data management subsystem. Inaccessible sensors that are identifiable components in the 1975 subsystem are the only exception. Because of their inaccessibility, these components must be augmented with some form of redundancy if they are essential to the mission. Degree "0" maintenance is recommended for these items. It is assumed that these will no longer be a problem in 1985, being integral with other

| MAINTENANCE CONCEPT / SUBSYSTEM | DEGREES OF MAINTENANCE | | | |
|---|---|---|---|---|
| | 0<br>PARALLEL REDUN | 1<br>STANDBY REDUN | 2<br>REMOVE & REPLACE | 3<br>REPAIR |
| COMMUNICATIONS | | R<br>(FS) ← → | 500 W TRANSMITTER<br>INTERCOM<br>(FS) | ANTENNAS,<br>WIRING<br>(FS) |
| CREW SUBSYSTEM | | | R | BUNKS, BEDDING,<br>TV TAPES, ETC. |
| DATA MANAGEMENT | INACCESSIBLE<br>SENSORS | | R<br>MODULARIZED<br>COMPUTER, DATA<br>ADAPTER | FILM PROCESSING<br>AND TV UNIT |
| ELECTRICAL POWER | DETERMINE DEGREE OF MAINTENANCE<br>BY COMPONENT<br>FS | FS | R<br>(FOR MOST ITEMS) | RADIATORS (FS) |
| EXPERIMENTS | (FS - PROBE<br>INTERNAL<br>REDUNDANCY) | | R<br>(PROBES)<br>FS ← → | ONBOARD<br>EXPERIMENTS<br>FS |
| EXTRAVEHICULAR<br>ACTIVITY | | | MMU, AMU, AEV<br>FS ← → | R<br>FS |
| MAINTENANCE<br>EQUIPMENT | | | R<br>FS ← → | FS |
| INFLIGHT TEST | | | R | |
| LIFE SUPPORT | | | R | TANKS, PLUMBING,<br>DUCTS |
| NAVIGATION AND<br>GUIDANCE | | R<br>FS ← → | ELECTRONIC<br>PACKAGES<br>FS | (FS - POSSIBLE<br>REPAIR OF<br>INERTIAL UNIT) |
| PROPULSION | TANKS, FLUID<br>EXPULSION<br>DEVICES FS | | R<br>FS ← → | FS |
| REENTRY | | | R<br>(FS - COMMONALITY<br>WITH MM ITEMS) | STRUCTURE, HEAT<br>SHIELD<br>FS |
| RENDEZVOUS AND<br>DOCKING | INCLUDED IN STRUCTURE SUBSYSTEM | | | |
| STABILITY CONTROL | | | R | |
| STRUCTURE | | | PORTS, WINDOWS,<br>ETC.<br>FS | R<br>FS |

R - RECOMMENDED, EXCEPT FOR ITEMS NOTED IN OTHER COLUMNS.

FS - FURTHER STUDY OR TRADE INDICATED

Figure 7.2-1: SUBSYSTEM MAINTENANCE CONCEPT MATRIX — 1975 Mars/Venus Flyby Mission



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| MAINTENANCE CONCEPT / SUBSYSTEM | DEGREES OF MAINTENANCE | | | |
|---|---|---|---|---|
| | 0 PARALLEL REDUN | 1 STANDBY REDUN | 2 REMOVE & REPLACE | 3 REPAIR |
| COMMUNICATIONS | | ALL OTHER ITEMS FS↔ | R (LASER ASSEMBLY) FS | TELESCOPE TUBE, ANTENNAS |
| CREW SUBSYSTEM | | | R | BUNKS, TV TAPES, ETC. |
| DATA MANAGEMENT | INTEGRAL NON-REPLACEABLE SENSORS (FS) | | R - MODULARIZED COMPUTER, ETC. | WIRING |
| ELECTRICAL POWER | MAINTENANCE CONCEPT SHOULD BE DETERMINED BY COMPONENT | | R | PCS UNIT, RADIATORS, ETC. (FS) |
| EXPERIMENTS | | | FS↔ | R FS |
| EXTRAVEHICULAR ACTIVITY | | | AMU, MMU, AEV FS↔ | R FS |
| MAINTENANCE EQUIPMENT | | | R F S↔ | FS |
| INFLIGHT TEST | | | R | |
| LIFE SUPPORT | | | R | RADIATORS, TANKS, DUCTS ETC. (FS) |
| NAVIGATION AND GUIDANCE | | R FS → | ELECTRONIC PACKAGES, (FS) INERTIAL UNIT | |
| PROPULSION | TANKS, FLUID EXPULSION DEVICES (FS) | | R (FS - NUCLEAR STAGE INSPECTION) | F S |
| REENTRY | | | R (FS) | STRUCTURE, HEAT SHIELD, ETC. (FS) |
| PLANETARY LANDER | | FURTHER STUDY REQUIRED | | |
| STABILITY CONTROL | CMG'S FS ↔ | FS | R (FS - CMG DRIVE AND TORQUING) | |
| STRUCTURE | | | WINDOWS, PORTS | R (FS) |

R - RECOMMENDED, EXCEPT FOR ITEMS NOTED IN OTHER COLUMNS.

FS - FURTHER STUDY OR TRADE INDICATED

Figure 7.2-2: SUBSYSTEM MAINTENANCE CONCEPT MATRIX — 1985 Mars Landing Mission

components or improved to a point where failure is unlikely. A second exception to the Degree "2" concept is Degree "3" repair of wiring and connectors.

Some major assemblies in the subsystem, such as the TV unit and the film processing unit, show a maintenance concept that closely borders on Degree "3" maintenance. The maintenance tasks for these items include such things as bearing replacement, clutch replacement, etc. These tasks could be considered as repair tasks, but it was assumed that the equipment could be designed so that these tasks could be accomplished on the installed equipment without too much difficulty.

Most of the equipment in the subsystem is electronic, and would lend itself to modularization and commonality of replaceable modules. It is most important that the data adapter and the computer be designed in this manner if the Degree "2" concept is to be effective. Significant weight increase is the penalty if this is not accomplished.

### 7.2.4 ELECTRICAL POWER SUBSYSTEM

Further study is necessary to determine the best maintenance concept for the electrical power subsystem. Degree "2" has been tentatively recommended as a point of departure. It is felt, however, that an overall concept for the subsystem may be misleading because of the number of exceptions and areas for further study that have been identified. Table 7.2-3 shows the electrical power subsystem equipment component list for the 1975 and 1985 time periods (integrated) and summarizes the basic component quantities, required parallel redundancy, and spares for the two time periods. Most of the parallel redundancy is synthetic to meet mission power level requirements as discussed in Section I.4 of the appendix. Because there is a requirement for only one spare for items like the inverters, the spare could be wired in with a switching capability (standby redundancy) with little penalty. Items such as the radiator require only one level of parallel redundancy, and items such as the structural repair kit require only one spare which should be allowed because of the implied repair necessity. Thus, it can be seen that there is a diversity of logical maintenance concepts in the subsystem and these must be determined for each component.

It can be noted from Table 7.2-3 that the power conversion system (PCS) unit of the 1975 mission was modularized for the 1985 mission. The combined rotating unit (CRU) was the only modularized item of the PCS unit that was spared, which leads one to believe that significant weight savings could be made for the 1975 mission if the PCS unit was designed so the CRU could be replaced. The CRU weighs between 20 and 45 kilograms versus about 245 kilograms for the complete PCS unit.

Repair of the Brayton cycle units could have a significant effect on the overall maintenance concept and on spacecraft design. Even though the PCS units are assumed to be repairable for the 1985 mission, it is not clear if they should be repaired in the unpressurized electrical power bay or brought into the spacecraft for repair. If they are in fact to be made repairable,

Table 7.2-3: ELECTRICAL POWER SUBSYSTEM EQUIPMENT COMPONENT LIST

| Component Nomenclature | 1975 Basic No. | 1975 Parallel Redundancy | 1975 Spares | 1985 Basic No. | 1985 Parallel Redundancy | 1985 Spares |
|---|---|---|---|---|---|---|
| Fuel Block | 2 | | | 1 | | |
| Shield | 1 | | | 1 | | |
| Fuel Recovery System | 2 | | | | | |
| PCS Unit | 1 | 1 | 1 | | | |
| CRU | | | | 1 | 1 | 1 |
| Gas Loops | | | | 1 | 1 | |
| Recuperator | | | | 1 | 1 | |
| Heat Sink HX | | | | 1 | 1 | |
| Heat Source HX | | | | 1 | 1 | |
| Duct System | | | | 1 | 1 | |
| Thermal Insulation | | | | 1 | 1 | |
| Argon/Water Glycol HX | 1 | 1 | | 1 | 1 | |
| Coolant Pump and Motor | 1 | 1 | 4 | 1 | 1 | 2 |
| Frequency Sensor | 1 | 1 | 7 | 1 | 1 | 2 |
| Parasitic Load | 1 | 1 | | 1 | 1 | |
| HV Transformer Rectifier | 1 | | 4 | 1 | | 3 |
| LV Transformer Rectifier | 1 | | 4 | 1 | | 3 |
| High-Voltage Regulator | 1 | | 3 | 1 | | 2 |
| Low-Voltage Regulator | 1 | | 3 | 1 | | 2 |
| Valves | 20 | | 3 | 20 | | 3 |
| Quick Disconnects | 10 | | 2 | 10 | | 2 |
| Evaporator System | 1 | | | | | |
| Inverter (Square Wave) | 1 | 1 | 1 | 1 | 1 | 1 |
| Inverter (Sine Wave) | 1 | 1 | 1 | 1 | 1 | 1 |
| Variable Frequency Inverter | 1 | 1 | 1 | 1 | 1 | 1 |
| Speed Control (CRU) | 1 | 1 | 2 | 1 | 1 | 2 |
| Relays | 40 | | 3 | 40 | | 3 |
| Structure and Supports | 1 | | | 1 | | |
| Structure Repair Kit | 1 | | 1 | 1 | | 1 |
| Radiator | 1 | 1 | | 1 | 1 | |
| Radiator Insulation and Attachment | 1 | | 1 | 1 | | 1 |
| Heat Dump Door Mechanism | 1 | | | 1 | | |
| Motor and Drive | 1 | 1 | | 1 | 1 | |
| Temp. Sensor and Control | 1 | 1 | | 1 | 1 | |
| Locking Actuator | 1 | | | 1 | | |
| Electrical Busses | 12 | | 2 | 20 | | 2 |
| Circuit Breakers | 113 | | 4 | 200 | | 5 |
| Wiring and Connectors---Power | 250 | 250 | | 400 | 400 | |
| Wiring and Connectors---Control | 850 | | 3 | 999 | | 3 |
| Wiring and Connectors---Inter. | 999 | | 4 | 999 | | 3 |
| Wiring and Connectors---Inter. | 999 | | 4 | 999 | | 3 |

a trade must be made to determine the repair site. There are a number of advantages to both repair locations:

1) Repair "in situ":

   a) Does not require moving the PCS unit into the spacecraft (with a high probability of handling damage).

   b) Does not require design of the airlock or spacecraft interior to accept the unit.

   c) Enables breaking the gas loops with low risk of contamination and no purge requirements.

2) Repair in spacecraft "workshop":

   a) Does not require multiple EVA excursions to complete the repair.

   b) Requires less suit expendables.

   c) Repair can be accomplished by one man with minor assistance.

   d) Repair can be accomplished with bare hands.

   e) Lighting is better and tools are readily accessible.

Repair "in situ" was selected as the baseline concept for the 1985 mission analyses.

### 7.2.5 EXPERIMENT SYSTEM

Degree "2" maintenance is tentatively recommended for the experiment subsystem in the 1975 time period. Further study is required into several aspects of the mission experiments. The planetary probes to be carried on the 1975 flyby missions may be designed in several ways. They might be designed with sufficient internal redundancies and radio-controlled operation modes that repair of the probes before launch need not be considered. Or, the probes might be designed for checkout and replacement of internal mechanisms before flight. Both of these concepts must be considered for further study.

Onboard experiments are assumed to lend themselves to repair or replacement maintenance concepts. Because of the flexibility that has been assumed for the onboard experiments, it is felt that they may be repaired without much difficulty, and Degree "3" maintenance is recommended for them. Degree "3" maintenance is also required for certain items such as the experiment airlock. Degree "2" is recommended because the probes and the onboard experiments are considered as exceptions to the general concept.

Planetary probes are not considered as a part of the 1985 landing missions; therefore, the onboard experiments will determine the general maintenance concept. For this reason, Degree "3" maintenance is recommended for the 1985 missions. It cannot be overemphasized that further study is required in determining the maintenance concept to be applied to experiments. The determination of this maintenance concept, and the nature of the experiments themselves, may

have a significant effect on the maintenance concepts selected for other subsystems. Several other subsystems could be considered for Degree "3" maintenance if there was little or no penalty associated with an onboard workshop. If the experiments require an onboard workshop, the penalty could be considered against the experiments and other subsystems could be designed to share the experimental workshop for Degree "3" maintenance. It is also possible that the best maintenance concept for the experiments is Degree "3" maintenance, which could justify Degree "3" maintenance for other borderline subsystems. The idea of justifying a workshop from the combined requirements of several subsystems applies to the 1975 as well as the 1985 time period.

### 7.2.6 EXTRAVEHICULAR ACTIVITY SUBSYSTEM

The extravehicular activity subsystem is essentially the same for both the 1975 and 1985 time periods, and Degree "3" maintenance is recommended for both. Degree "3" maintenance for this equipment will not require a workshop, although it may require some special provisions on the holding and stowage brackets for the larger items, such as the backpacks. The powered locomotion units will be repaired by simple replacement of major parts (Degree "2" maintenance). Further study between Degree "2" and "3" maintenance is required for this subsystem.

### 7.2.7 MAINTENANCE EQUIPMENT SUBSYSTEM

Degree "2" maintenance is recommended for this subsystem, although as the equipment becomes better defined, further investigation into Degree "3" maintenance is necessary.

### 7.2.8 INFLIGHT TEST SUBSYSTEM

Without exception or qualification, Degree "2" maintenance is recommended for this subsystem. Degree "3" maintenance is felt to be unnecessary, and lesser degrees of maintenance have problems associated with them (for example, the large increase in panel size and possibility of confusion when designing redundant indicators). A more detailed discussion is provided in Section I.7 of the appendix.

### 7.2.9 LIFE SUPPORT SUBSYSTEM

This subsystem (which includes environmental control as well as life support functions) is felt to be a key factor in spacecraft interior design. Degree "2" maintenance is tentatively recommended for it during both time periods of interest; however, some elements of the subsystem require Degree "3" maintenance, and if the weight and cost penalties for a workshop can be justified for some other subsystem (or combination of subsystems), Degree "3" maintenance may be desirable.

The placement of the life support subsystem in the spacecraft is felt to be critical. Poor placement can cause maintenance time on the subsystem to increase excessively, and the probability of maintenance error and damage to

the equipment can increase inordinately. Section I.8 in the appendix provides additional discussion on this point.

### 7.2.10 NAVIGATION AND GUIDANCE SUBSYSTEM

Degree "1" maintenance is recommended with some minor exceptions in both 1975 and 1985 missions. Electronic portions of the subsystem should be made replaceable because they lend themselves well to the Degree "2" concept. The backup equipment, manual sextants, etc., also fall in this category. The major problem in specifying a maintenance concept is the stable platform. Nine additional platforms are required to achieve the mission reliability goals. These platforms could be designed for standby redundancy or as spares. Replacement of the platforms as spares could be a problem because of platform alignment requirements. It may not be possible to achieve the required accuracy of alignment with a replaceable unit. It is tentatively recommended that one level of standby redundancy be provided, with the basic unit designed for replacement and backed up by spares. The standby unit could be operated while the basic unit is replaced and proper alignment verified, and then the standby unit could be shut down until another failure occurs. This concept requires further study.

An alternate concept would be to provide a standby inertial unit, and provide a repair capability for the failed units. This concept would work much like the one discussed above, except that instead of replacing the failed basic unit with a spare, it would be removed and the failure repaired at a workshop facility. The repaired basic unit would then be reinstalled, aligned, and reactivated. Again, this concept requires further study.

### 7.2.11 PROPULSION SUBSYSTEM

Degree "2" maintenance is recommended for the propulsion subsystem. Areas of further study and exceptions to the recommended concept include inaccessible items such as fluid expulsion devices, and large or bulky items such as tankage and some parts of the midcourse engine(s). In general, it is felt that Degree "2" maintenance is possible if the equipment is designed with this concept in mind. The possibility of conducting Degree "3" maintenance should be investigated.

The major problems for either concept will be providing accessibility to replaceable parts, providing malfunction and leak detection capability, and providing means of containing or neutralizing entrapped fluids that might be released during repairs. Major propulsion stages such as the injection stage, and the Mars capture stages for the 1985 mission, have not been considered as repairable. Inspection of these stages has been considered, but it has not been determined what could be accomplished by an inspection if repair is not anticipated. In the case of nuclear stages, it has not been determined if an inspection can be conducted.

### 7.2.12 EARTH REENTRY SUBSYSTEM

In general, Degree "2" maintenance is recommended for the command module (CM) and the Earth reentry vehicle (ERV). Most of the subsystems within the ERV can be broken down into replaceable modules. Exceptions to this are the vehicle structure and heat shield, and the chutes and ground landing provisions. It will be difficult or impossible to check out these items, and redundancy or overdesign is recommended. Damage to the structure and the heat shield due to docking operations or meteoroid impacts could be repaired (with difficulty). It is possible that many elements of the ERV could be designed to be common with replaceable items on board the mission module and spares requirements could be reduced in this manner. Further study in this area is recommended.

### 7.2.13 RENDEZVOUS AND DOCKING SUBSYSTEM

This subsystem was not separately identified for either time period. In the 1975 time period, the elements of the subsystem were included under the structure subsystem. This was also done for the ERV in the 1985 time period, but there are additional docking and rendezvous requirements associated with the planetary landing vehicle that were not determined in detail for this study.

### 7.2.14 PLANETARY LANDING VEHICLE (MEM)

No detailed study of the MEM was conducted; however, certain observations regarding maintenance concepts can be made. Actually, maintenance concepts for two distinct phases of operation must be considered. First, the concept for maintenance before the MEM leaves the parent vehicle must be considered. It is expected that the MEM will be subjected to a rigorous checkout before it departs for the planetary surface. The results of this checkout may indicate that maintenance is required. The concept for this phase could reasonably be Degree "2" maintenance, particularly if the MEM equipment is designed for a high degree of commonality between the mission module (MM) and the ERV equipment.

Second, the concept for maintenance while the MEM is separated from the MM must be considered. It is expected that a second checkout via communications link will be accomplished before the MEM leaves the planetary orbit. Degree "2" maintenance might also be accomplished here with transfer of required parts accomplished extravehicularly. While the MEM is in transit to and from the planet's surface, there will be no time for maintenance other than manual selection of standby units or alternate modes of operation. During the stay on the planet's surface, it is desirable to minimize the maintenance that could be performed. For the shorter-duration surface missions (20 to 30 days), combinations of parallel and standby redundancy should raise the vehicle reliability to an acceptable level.

### 7.2.15 STABILITY AND CONTROL SUBSYSTEM

Degree "2" maintenance is recommended for the stability and control subsystem without exception during the 1975 interplanetary mission. This subsystem is primarily electronic and can be modularized for easy replacement of packages.

On the 1985 Mars landing mission, Degree "2" maintenance is recommended for the electronic part of this subsystem. Also, the stability and control subsystem will include control-moment gyros (CMG's), which do not lend themselves to repair as well as the electronic parts of the subsystem. The CMG masses will probably not fail; however, the drive motors and torquers must be considered for redundancy or replacement. Spares requirements for these items were relatively small, and standby redundancy could be considered. Standby redundancy for each drive motor and torquer might be desirable, but it is questionable if standby redundancy for the CMG bearings could be accomplished. It is felt that bearing replacement will be required, and once a maintenance capability is provided on the bearings, replacement of the motors and torquers should be relatively simple. Therefore, Degree "2" maintenance is recommended for these items, although further study seems in order.

### 7.2.16 STRUCTURE SUBSYSTEM

Degree "3" maintenance is recommended for the structure subsystem. To permit Degree "3" structural maintenance, further study is required to determine typical repair actions and techniques to be employed. Some exceptions to Degree "3" maintenance are the replacement of ports and windows, and elements of the rendezvous and docking equipment. These are borderline cases, but are defined as requiring Degree "2" maintenance.

# 8.0 MAINTENANCE PHILOSOPHY AND DESIGN PRECEPTS COMMON TO ALL MISSIONS

## 8.1 GENERAL DISCUSSION

The maintenance philosophy selected for a mission significantly affects the approach taken in the basic design of the spacecraft. If a concept of no maintenance is assumed, then the spacecraft must include parallel or standby redundant components, with automatic or remotely controlled switchover capability for all spacecraft functions that must operate for the duration of the mission. For long mission durations this can result in an excessively complex and heavy configuration (see Section 4.0).

Even when man is available to perform maintenance activities, there can be a considerable difference in the level of maintenance involved that affects the fault detection and isolation capability provided, the replaceable component level designed into the system, the crew skills involved, etc. The ultimate design for ease of maintenance would be an automatic fault isolation capability that would be able to identify any item that might have to be replaced. However, this is at present not practicable and therefore some intermediate approach must be taken. Where feasible, such as for electronic-type equipment, it was assumed as a study expediency that the on-board inflight test subsystem (which includes display panel indications) would isolate a failure to the replaceable component level, realizing that certain design problems may be implicit in such an approach. Otherwise it was assumed that test points would be available so that, through use of maintenance and test equipment, a fault could be isolated to the replaceable level. Other assumptions and guidelines used that can affect the design approach are included in Section 3.0. The replaceable component level considered in this study is as identified in the data sheets contained in Volume III. Notes on these data sheets indicate where it was felt that a higher or lower level of component replacement might be considered. In a number of instances these variations were analyzed during the study. The results of these analyses are presented in Sections 5.0 and 6.0.

In some cases it may actually be possible to perform some repair on a failed component after it has been removed, such as replacement of seals, mechanical linkages, solenoids, bearings, etc. However, a more detailed analysis than was possible during this study would be required. For long-duration unresupplied missions such as planetary flights, a limited second-level (Degree "3") repair capability requiring the addition of a maintenance shop or work bench might be practical in some cases. But for Earth-orbit missions, which include regular resupply, a Degree "3" capability is not considered to be advantageous. Past ground-based experience has shown a Degree "3" maintenance (bench maintenance) capability to be economically effective only when a large number of failures of like components are involved. The number of similar failures that can be expected during a single spacecraft mission do not justify a bench repair capability. This is borne out by the limited unscheduled maintenance that resulted from the mission simulations described in Sections 5.0 and 6.0.

In general, selecting a maintenance philosophy requires consideration of several factors. These include:

- Knowledge of mission objectives.
- Mission effects on system/subsystem design.
- Mission demands on crew time.
- Technical capabilities of the crew to provide maintenance.
- Feasible level of maintenance action and associated demands on packaging concepts.
- An estimate of the inherent reliability of the subsystem hardware (failure rates and useful life) and configuration.
- Safety implications associated with alternate maintenance philosophies that are considered.
- An estimate of equipment allowable downtimes and repair/restoration times (repair time distributions and math models used to evaluate probability of no system failure due to exceeding the allowable downtime).

The optimum maintenance philosophy for a stated mission will be based on the most effective blend of the parameters that measure the influence of these factors. Section 7.0 discusses the maintenance philosophies or concepts that were thought to be most effective for the subsystems of the missions selected for this study. Section 8.2, which follows, summarizes those maintenance philosophies that were found to be common to all the missions studied.

Once it has been determined that on-board maintenance is necessary to meet the numerical requirement for probability of mission success, the next step is to impose requirements on component/subsystem design that will ensure the success of the maintenance actions to be performed. The analyses conducted as a part of this study have resulted in a number of observations of general design principles necessary to ensure maintainability of the spacecraft systems. These are presented in Section 8.3. Some design precepts assumed during the performance of the study are in Section 3.4.4.

## 8.2 MAINTENANCE PHILOSOPHY COMMON TO ALL MISSIONS

1) Plan maintenance on a remove-and-replace (Degree "2") basis whenever practicable. Component packaging must be at a level which will facilitate this concept. Use special maintenance kits only for repairs of large, bulky items for which a remove-and-replace concept may not be desirable; e.g., structural parts, plumbing, ducts, large tanks, etc.

2) With relatively few exceptions, an on-board bench repair (Degree "3" maintenance) capability is not justified. Exceptions must be evaluated individually, since most unscheduled maintenance requirements are insufficient to warrant such a capability. Component replacement requiring EVA, in which the removed assemblies are returned to the bench where Degree "3" maintenance can be performed in a shirtsleeve environment; or situations where the experiments subsystem requires an on-board workshop and other sub-

systems can be designed to take advantage of its availability, may be considered for Degree "3" maintenance.

3) Use scheduled maintenance only when other means of attaining desired assurance levels are too costly in terms of weight (spares, expendables), crew time, cost, and reliability of affected systems.

4) When only one spare of an item is required to achieve the desired level of assurance, consider making the spare standby-redundant so it can be switched into the system when the main item fails. This will eliminate a remove-and-replace maintenance action. Each individual instance will have to be evaluated as it may not be practical to make all single-spare components standby-redundant. The concept is particularly applicable to Earth-orbit missions where a spare can be provided at the next resupply.

5) Give unscheduled maintenance precedence over scheduled maintenance; i.e., unscheduled maintenance has first priority over maintenance resources including crew skills, except where unscheduled maintenance of nonsafety critical items logically is preempted by scheduled maintenance of safety critical items.

6) Make available fully detailed procedures for all scheduled and expected unscheduled maintenance functions.

7) Provide adequate spares to ensure the required probability of crew survival and mission success.

## 8.3 DESIGN PRECEPTS COMMON TO ALL MISSIONS

The principles given below augment the assumptions listed in Section 3.2, many of which likewise should be considered seriously when undertaking spacecraft design.

1) Place Emphasis on Design of Life Support Subsystem---The life support subsystem, which included life support and environmental control in this study, is the major source of scheduled and unscheduled maintenance workload. In addition, it requires an extended period of training to develop the necessary operation and maintenance skill. Spacecraft interior design should be planned about a life support subsystem configuration and location that optimizes operation and maintenance. Optimum location of the life support subsystem is discussed in more detail in Section 7.2.9.

2) Modularize High Failure Items---Equipment should be modularized whenever it can be broken down in a number of identical modules. The greater the number of identical modules, the more effective is the use of spares, and initial spares weight provided for a mission is reduced considerably. Modularization also should be aimed at grouping high-failure-rate components into replaceable, low-weight modules.

3) Design for Commonality of Spacecraft Components---Achieve commonality of components, within and between subsystems, whenver possible. Spares requirements decrease significantly when a high degree of commonality can be attained. For example, electronic subsystems could standardize on a small variety of amplifier modules that would be replaceable and common between the subsystems. The electrical characteristics of such a common

module could be altered by pin connections used by particular installations. The objective would be to minimize the number of types of spares that will increase the spares use and result in a reduction in overall spares weight required.

4) Design for Commonality of Experiment and Spacecraft Equipment---In planning experiment programs and identifying the equipment required, use items which are common with spacecraft system equipment wherever possible. Better use of equipment, less cost, and fewer spares to support the spacecraft and experiments will result.

5) Spare Heavy Noncritical Items Only at Resupply---For some large items of equipment, where the probability of failure is quite remote, only one spare is necessary to achieve the desired assurance of mission success. If resupply is available and failure of the item can be tolerated for a number of days by using an alternate mode of operation, the practicability of not providing a spare initially should be considered. If the item fails, a spare can be brought up at the next resupply.

6) Minimize EVA---In the interest of reducing EVA, place high-failure-rate and long-maintenance-time items within the pressure hull whenever practical. When EVA is required to perform maintenance, the replaceable components should be packaged in a size and shape that can be conveniently handled by a pressure-suited man. In this case, modularizing equipment into packages that are too small to be handled conveniently would not be desirable unless the advantage to be gained is considerable.

7) Reduce Hazards to Personnel During EVA---Solar panels, antennas, and other large equipment mounted on the exterior surfaces of the spacecraft present a hazard to personnel moving about during EVA. Design such equipment to withstand an inadvertent impact, and minimize the hazards to a pressure-suited man by such means as eliminating unprotected sharp surfaces and making surfaces easily visible under all lighting conditions.

8) Design Airlock for at Least Two Men---It is assumed that EVA will require two workers for maximum safety (the "buddy" system). Accordingly, design airlocks for a minimum of two spacesuited men and arrange for the doors to interlock (permitting only one to open at a time) unless the cabin pressure is dumped. An override for the interlock is desirable, but should be activated only through a special sequence eliminating change activation. The override must be operable from both sides of the lock. All airlock operations, except pumpdown, should be independent of the spacecraft electrical power system.

9) General Interior Design---Provide protection for all switches and controls against inadvertent activation. Plan all maintenance tasks that could possibly cause loss of cabin pressure, and design the equipment so that functions can be performed by spacesuited personnel; for example, airlock interior seal replacement. Also, consider compartmented design to reduce the possibility of catastrophic failure throughout the spacecraft. Numerous assumptions involving general spacecraft interior design that were made at the beginning of this study are listed in Section 3.2. In general, a spacecraft interior design that incorporates all of the features mentioned will greatly improve maintainability.

10) Develop Alternate Design of Panel Display Indicators---When designing fault indication and status displays, consider electromechanical flags and solid-state lights as well as a fault matrix display, as alternatives to a conventional display with indicator lamps. Lamps can be chosen for relatively low failure rates, but the number of lamps required makes failures likely. The replacement of bulbs takes only a short time, but failures must first be detected, and frequent replacement can be a major nuisance.

11) Identify Fasteners Selectively---Limit fasteners for all items that can be maintained to a few common types and sizes, to minimize tool requirements. Fasteners for items requiring removal by a spacesuited man should be as large as practical and few in number. Screw type fasteners, which permit the tool to torque out of the fastener, are not recommended for zero-g use. Such fasteners require application of both torque and axial force, complicating the task unnecessarily. For scheduled maintenance items and high-failure-rate items, removal without the use of tools is desirable. "Pip-pin" fasteners can be used when fitting tolerances are not critical and the fastener is loaded in shear only. Guide pins and cam lock fasteners can be used for close tolerance replacements.

12) Limit Electrical Connections---No EVA repair of connectors or plugs should be planned. For interior electrical connections wire-wrap or crimp (one or the other) connections should be used to permit inflight repair without soldering.

# 9.0 COST ANALYSIS

## 9.1 BACKGROUND DATA AND ESTIMATING TECHNIQUES

### 9.1.1 BASIC APPROACH

The groundrules and estimating assumptions used in obtaining total program cost were generally based on the Douglas MORL mission described in Reference 1. More specific groundrules are detailed under the following costing discussions for each of the missions considered during this study: 1975 near-Earth orbital mission, 1985 $L_1$ Libration Center mission, 1975 Mars/Venus flyby mission, and 1985 Mars landing mission.

In general, emphasis in the estimating effort was placed on the mission vehicle and on arriving at subsystem and software relative cost numbers to maintain a basic assigned system, a maintainable system with selected redundancies, and a redundant system. These systems were further broken down and estimated by subsystem and component as defined on the MARCEP data sheets.

The total systems program cost tables, such as given in Tables 9.2-1 and 9.2-2 for the 1975 near-Earth orbital mission, were developed for each program to show costing trends between programs and major program elements. The total systems program costs do not include development costs for launch vehicles, new tracking stations, or mission control centers, etc. For example, if a satellite communication relay network or new laser tracking stations were used to fulfill mission requirements, these would be considered already developed and costed under other programs.

Some costs were included for test demonstration, but a large-scale test program was not estimated. A complete flight test program, if estimated in detail, could increase the total program costs considerably. Therefore, total program costs should be considered as budgetary or planning estimates only.

Costs excluded from the estimates used in this study are as follows:

1) Crew costs--training, yearly salary, etc.
2) Launch vehicle development for the S-1B, S-1B uprated, Saturn V, and Saturn V-25S.
3) Facility Development--launch site, tracking stations, mission control center, etc.
4) Initial recovery task force (ships, airplanes, etc.)
5) Experiments--development, hardware, integration, and operation.
6) Fuels (including nuclear) and gases for the mission vehicle and launch vehicle.
7) Planetary lander (MEM)--propulsion modules and tanker development.
8) Assembly and docking units where required.

### 9.1.2 ESTIMATING TECHNIQUE

The costing performed to determine unit relative cost values and developmental costs was derived from a combination of parametric and detail estimating techniques. Parameters are defined as sets of values based on statistical data, expressing a relationship between variables, both dependent and independent. These are developed by direct application of experience actuals, extrapolation of historical data, detailed estimates of comparable systems, and other similar information sources. These values are then expressed as a relationship to dollars or manhours against weight, size, time, etc., to form a coordinate system within which the relationship is expressed as a median line, or a set of limits.

The parametric approach was used in estimating the total systems cost as well as a checkpoint for verifying the total mission vehicle cost. The parameters were derived from actual data or best estimated data for each subsystem in the Apollo CSM, LEM, MORL, Gemini, MOL, and other programs. Cost data was then correlated to one or more subsystem characteristics and plotted by subsystem. With this information the total mission vehicle cost by subsystem was estimated. Each subsystem was then apportioned a relative cost number in accordance with the foregoing data so that the total for the mission vehicle equaled 1.000.

The total mission vehicle subsystem hardware relative cost numbers were developed using MORL subsystem cost data from the Douglas reports as a guide. The subsystem relative cost numbers were further broken down into component callouts as outlined in the MARCEP data sheets by direct comparison to similar types of components used in other estimated Boeing space programs. The components for the basic system were estimated using a weight relationship to specific categories within each subsystem. For example, the communications subsystem was broken into a telemetry unit, voice communications unit, television system, etc. The components within each unit were then estimated by using engineering complexity factors and weight relationships. As the component quantities increased for the Degree 0 and Degree 2 maintenance concept during the analysis, the relative values of the respective systems were adjusted so that final values would total to 1.00. The component level of estimating was performed to analyze relative cost comparison increases required by quantity changes to obtain maintainable systems with selected redundancies. The relative cost number of 1.00 represents the costs associated with the development, hardware, and operations required to obtain one operational mission vehicle.

## 9.2 1975 NEAR-EARTH ORBITAL MISSION

### 9.2.1 INITIAL COST FOR A 90-DAY RESUPPLY MISSION

The total systems program cost (dollars in millions) is shown in Table 9.2-1, for a 5-year program with 90-day resupply capability. The initial cost category includes the total estimated costs required to achieve this mission operation, which are categorized as follows:

A) Mission vehicle equal to 1.000 and further broken down in Table 9.2-4. The mission vehicle costs include:

1) Development

   a) Subsystem developmental costs including AGE development.

   b) Estimated flight test demonstration including one spare mission vehicle.

   c) Development of software and launch site support.

2) Hardware--One mission vehicle estimated by subsystem.

3) Operation--Operational set of AGE and associated sustaining effort for the software and launch site support.

B) Reentry vehicle includes:

1) Basic developmental costs to obtain an eight-man vehicle.

2) Flight test demonstration to obtain a qualified system.

3) Development of associated AGE and an operational set.

4) Costs for the initial operational reentry vehicle.

5) System and subsystem integration.

C) Logistics Module:

1) Basic developmental costs to obtain an operational logistics module.

2) Flight test demonstration in conjunction with the reentry vehicle where possible.

3) Costs for the initial operational logistics module.

4) Development of associated AGE and an operational set.

5) System and subsystem integration.

D) Launch Vehicles:

1) Flight test vehicles as required to obtain qualified reentry and logistics modules.

2) Costs for the initial launch vehicle.

E) Operations

1) Operations for the flight test demonstration.

2) Three years of downrange tracking and data acquisition costs accumulated during the test demonstration and initial launch.

3) Recovery operations for the test demonstration.

### 9.2.2 RESUPPLY COST FOR A 90-DAY RESUPPLY MISSION

The resupply cost category shown in Table 9.2-1 includes total estimated costs required to supply the mission vehicle every 90 days for a 5-year period, which are categorized as follows:

A) Mission Vehicle---Costs associated with the resupply spares packages required every 90 days.

B) Reentry Vehicle---Costs associated with 20 resupply vehicles and sustaining AGE.

C) Logistics Vehicle---Costs associated with 20 resupply vehicles and sustaining AGE.

D) Launch Vehicle---Costs associated with 20 resupply vehicles and sustaining AGE.

E) Operations

1) Launch operating costs for 20 resupply vehicles.

2) Five years of downrange tracking and data acquisition costs accumulated during the resupply period.

3) Five-year costs for recovery operations every 90 days during the resupply period.

### 9.2.3 INITIAL COST FOR A 180-DAY RESUPPLY MISSION

Table 9.2-2 gives total system program costs for a 5-year program with 180 days resupply capability. The initial cost category includes the total estimated costs required to achieve this mission operation, which are categorized as follows:

A) Mission Vehicle--Increased according to subsystem variances, to the mission vehicle described in Table 9.2-4, and itemized on Table 9.2-5.

B) Reentry Vehicle--The same as for the 90-day resupply period (9.2.B).

C) Logistics Module--The same as for the 90-day resupply period (9.2.C), except that the module is increased to carry 155 kilograms more spares.

D) Launch Vehicle--The same as for the 90-day resupply period (9.2.D).

E) Operations--The same as for the 90-day resupply period (9.2.E).

Table 9.2-1: 1975 NEAR-EARTH ORBITAL MISSION--90-DAY RESUPPLY

Total Systems Program Cost
(Dollars in Millions)

| | Initial | Resupply |
|---|---|---|
| Mission Vehicle | $2,752 | $ 20 |
| Reentry Vehicle | 1,762 | 905 |
| Logistics Module | 304 | 153 |
| Launch Vehicles | 454 | 620 |
| Operations | 827 | 1,191 |
| Total | $6,099 | $2,889 |

Table 9.2-2: 1975 NEAR-EARTH ORBITAL MISSION--180-DAY RESUPPLY

Total Systems Program Cost
(Dollars in Millions)

| | Initial | Resupply |
|---|---|---|
| Mission Vehicle | $2,759 | $ 16 |
| Reentry Vehicle | 1,762 | 472 |
| Logistics Module | 319 | 86 |
| Launch Vehicles | 454 | 310 |
| Operations | 829 | 1,125 |
| Total | $6,123 | $2,009 |

### 9.2.4 RESUPPLY COST FOR A 180-DAY RESUPPLY MISSION

The resupply cost category shown in Table 9.2-2 includes total estimated costs required to resupply the mission vehicle every 180 days for a 5-year period, which are categorized the same as for the 90-day resupply period, except that the quantities have been reduced to accommodate ten resupplies.

### 9.2.5 MISSION VEHICLE RELATIVE COST NUMBERS

Table 9.2-3 shows the mission vehicle relative cost numbers for the basic system (with no redundancy or spares) by subsystems, AGE and spares, test demonstration, software, and launch site support. The total relative cost number includes the development, unit hardware, and operations required to obtain a mission vehicle with no redundancy or spares, and is given here only to represent the baseline system before adding a realistic spares system for the 90- and 180-day resupply periods.

Table 9.2-4 shows the mission vehicle relative cost numbers for a maintainable system with selected redundancies for a 90-day resupply interval. The total relative cost figures given for the items listed on Tables 9.2-3 and 9.2-4 can be directly associated with the total initial cost for the mission vehicle given in Table 9.2-1, and the total relative cost number of 1.00 can be equated to the initial cost dollars shown for the mission vehicle.

Table 9.2-5 shows the mission vehicle relative cost for a maintainable system with selected redundancies for a 180-day resupply interval, and can be directly associated with the total initial cost for the mission vehicle given in Table 9.2-2.

## 9.3 1985 $L_1$ LIBRATION CENTER MISSION

### 9.3.1 INITIAL COST FOR A 180-DAY RESUPPLY MISSION

The total systems program costs (dollars in millions) is shown in Table 9.3-1 for a 5-year program with 180-day resupply capability. The initial cost category includes the total estimated costs required to achieve this mission operation, which are categorized as follows:

A) Mission vehicle equal to 1.00 and further broken down in Table 9.3-4. The mission vehicle costs include:

Table 9.2-3: 1975 NEAR-EARTH ORBITAL MISSION

Mission Vehicle Relative Cost Number
Basic System--With No Redundancy or Spares

| | Development | Hardware | Operation | Total |
|---|---|---|---|---|
| SUBSYSTEMS | | | | |
| Life Support System | 0.121 | 0.002 | | 0.123 |
| Communications | 0.095 | 0.001 | | 0.096 |
| Crew System | 0.008 | Negligible | | 0.008 |
| Data Management | 0.014 | 0.001 | | 0.015 |
| Electrical Power | 0.027 | 0.005 | | 0.032 |
| Extravehicular Activity | 0.023 | 0.001 | | 0.024 |
| Inflight Test | 0.001 | Negligible | | 0.001 |
| Maintenance Equipment | 0.001 | Negligible | | 0.001 |
| Propulsion | 0.040 | 0.001 | | 0.041 |
| Rendezvous and Docking | 0.008 | 0.001 | | 0.009 |
| Stability and Control | 0.116 | 0.003 | | 0.119 |
| Structure | 0.038 | 0.006 | | 0.044 |
| AGE | 0.059 | | 0.003 | 0.062 |
| TEST DEMONSTRATION | 0.063 | | | 0.063 |
| SOFTWARE | | | | |
| Computer Programming | Negligible | | Negligible | Negligible |
| Training Equipment | 0.002 | | Negligible | 0.002 |
| Simulation Equipment | 0.004 | | Negligible | 0.004 |
| Training | Negligible | | Negligible | Negligible |
| Technical Data | Negligible | | Negligible | Negligible |
| LAUNCH SITE SUPPORT | 0.039 | ____ | 0.002 | 0.041 |
| Total | 0.659 | 0.021 | 0.005 | 0.685 |

Table 9.2-4: 1975 NEAR-EARTH ORBITAL MISSION

Mission Vehicle Relative Cost Number
Maintainable System--Degree "2" Maintenance (90-Day Resupply Interval)

| | Development | Hardware | Operation | Total |
|---|---|---|---|---|
| SUBSYSTEMS | | | | |
| Life Support System | 0.187 | 0.003 | | 0.190 |
| Communications | 0.147 | 0.002 | | 0.149 |
| Crew System | 0.012 | 0.001 | | 0.013 |
| Data Management | 0.022 | 0.004 | | 0.026 |
| Electrical Power | 0.042 | 0.005 | | 0.047 |
| Extravehicular Activity | 0.036 | 0.001 | | 0.037 |
| Inflight Test | 0.002 | Negligible | | 0.002 |
| Maintenance Equipment | 0.001 | Negligible | | 0.001 |
| Propulsion | 0.062 | 0.001 | | 0.063 |
| Rendezvous and Docking | 0.012 | 0.003 | | 0.015 |
| Stability and Control | 0.180 | 0.006 | | 0.186 |
| Structure | 0.060 | 0.006 | | 0.066 |
| AGE | 0.091 | | 0.004 | 0.095 |
| TEST DEMONSTRATION | 0.063 | | | 0.063 |
| SOFTWARE | | | | |
| Computer Programming | Negligible | | Negligible | Negligible |
| Training Equipment | 0.002 | | Negligible | 0.002 |
| Simulation Equipment | 0.003 | | 0.001 | 0.004 |
| Training | Negligible | | Negligible | Negligible |
| Technical Data | Negligible | | Negligible | Negligible |
| LAUNCH SITE SUPPORT | 0.039 | ——— | 0.002 | 0.041 |
| Total | 0.961 | 0.032 | 0.007 | 1.000 |

Table 9.2-5: 1975 NEAR-EARTH ORBITAL MISSION

Mission Vehicle Relative Cost Number
Maintainable System--Degree "2" Maintenance (180-Day Resupply Interval)

| | Development | Hardware | Operation | Total |
|---|---|---|---|---|
| SUBSYSTEMS | | | | |
| Life Support System | 0.187 | 0.004 | | 0.191 |
| Communications | 0.147 | 0.002 | | 0.149 |
| Crew System | 0.012 | 0.001 | | 0.013 |
| Data Management | 0.022 | 0.004 | | 0.026 |
| Electrical Power | 0.042 | 0.005 | | 0.047 |
| Extravehicular Activity | 0.036 | 0.001 | | 0.037 |
| Inflight Test | 0.002 | Negligible | | 0.002 |
| Maintenance Equipment | 0.001 | Negligible | | 0.001 |
| Propulsion | 0.062 | 0.002 | | 0.064 |
| Rendezvous and Docking | 0.012 | 0.003 | | 0.015 |
| Stability and Control | 0.180 | 0.007 | | 0.187 |
| Structure | 0.060 | 0.006 | | 0.066 |
| AGE | 0.091 | | 0.004 | 0.095 |
| TEST DEMONSTRATION | 0.063 | | | 0.063 |
| SOFTWARE | | | | |
| Computer Programming | Negligible | | Negligible | Negligible |
| Training Equipment | 0.002 | | Negligible | 0.002 |
| Simulation Equipment | 0.003 | | 0.001 | 0.004 |
| Training | Negligible | | Negligible | Negligible |
| Technical Data | Negligible | | Negligible | Negligible |
| LAUNCH SITE SUPPORT | 0.039 | ——— | 0.002 | 0.041 |
| Total | 0.961 | 0.035 | 0.007 | 1.003 |

1) Development

   a) Subsystem developmental costs including AGE development.

   b) Estimated flight test demonstration including one spare mission vehicle.

   c) Development of software and launch site support.

2) Hardware--One mission vehicle estimated by subsystem.

3) Operation--Operational set of AGE and associated sustaining effort for the software and launch site support.

B) Reentry Vehicle includes:

1) Basic developmental costs to obtain an eight-man vehicle.

2) Flight test demonstration to accomplish a qualified system.

3) Development of associated AGE and an operational set.

4) Costs for the two initial operational reentry vehicles.

5) System and subsystem integration.

C) Logistics Module

1) Basic developmental costs to obtain an operational logistics module.

2) Flight test demonstration in conjunction with the reentry vehicle where possible.

3) Costs for the initial operational logistics module.

4) Development of associated AGE and an operational set.

5) System and subsystem integration.

D) Launch Vehicles

1) Flight test vehicles as required to obtain qualified reentry and logistics modules.

2) Costs for the initial launch vehicles.

E) Operations

1) Operations for the flight test demonstration.

2) Three years of downrange tracking and data acquisition costs accumulated during the test demonstration and initial launch.

3) Recovery operations for the test demonstration.

### 9.3.2 RESUPPLY COST FOR A 180-DAY RESUPPLY MISSION

The resupply cost category shown in Table 9.3-1 includes total estimated costs required to supply the mission vehicle every 180 days for a 5-year period, which are categorized as follows:

A) Mission Vehicle--Costs associated with the resupply spares packages required every 180 days.

B) Reentry Vehicle--Costs associated with ten resupply vehicles and sustaining AGE.

C) Logistics Vehicle--Costs associated with ten resupply vehicles and sustaining AGE.

D) Launch Vehicle--Costs associated with ten resupply vehicles and sustaining AGE.

E) Operations

1) Launch operating costs for ten resupply vehicles.

2) Five years of downrange tracking and data acquisition costs accumulated during the resupply period.

3) Five-year costs for recovery operations every 180 days during the resupply period.

### 9.3.3 INITIAL COST FOR A 360-DAY RESUPPLY MISSION

Table 9.3-2 gives total system program costs for a 5-year program with 360-day resupply capability. The initial cost category includes the total estimated costs required to achieve this mission operation, which are categorized as follows:

A) Mission Vehicle--Increased according to subsystem variances to the mission vehicle described in Table 9.3-4, and itemized on Table 9.3-5.

B) Reentry Vehicle--The same as for the 180-day resupply period (9.3.B).

C) Logistics Module--The same as for the 180-day resupply (9.3.C), except that the module is increased to carry 30 kilograms more spares.

D) Launch Vehicle--The same as for the 180-day resupply (9.3.D).

E) Operations--The same as for the 180-day resupply (9.3.E).

### 9.3.4 RESUPPLY COST FOR A 360-DAY RESUPPLY MISSION

The resupply cost category shown in Table 9.3-2 includes total estimated costs required to resupply the mission vehicle every 360 days for a 5-year period, which are categorized the same as for the 180-day resupply period, except that the quantities have been reduced to accommodate five resupplies.

### 9.3.5 MISSION VEHICLE RELATIVE COST NUMBERS

Table 9.3-3 shows the mission vehicle relative cost numbers for the basic system (with no redundancy or spares) by subsystems, AGE and spares, test demonstration, software, and launch site support. The total relative cost number includes the development, unit hardware, and operations required to obtain a mission vehicle with no redundancy or spares, and is given here only to represent the baseline system before adding a realistic spares system for the 180- and 360-day resupply periods.

Table 9.3-1: 1985 $L_1$ LIBRATION CENTER MISSION--180-DAY RESUPPLY

Total Systems Program Cost
(Dollars in Millions)

| | Initial | Resupply |
|---|---|---|
| Mission Vehicle | $2,518 | $ 7 |
| Reentry Vehicle | 2,436 | 533 |
| Logistics Module | 319 | 86 |
| Launch Vehicles | 854 | 918 |
| Operations | 872 | 1,130 |
| Total | $6,999 | $2,674 |

Table 9.3-2: 1985 $L_1$ LIBRATION CENTER MISSION--360-DAY RESUPPLY

Total Systems Program Cost
(Dollars in Millions)

| | Initial | Resupply |
|---|---|---|
| Mission Vehicle | $2,525 | $ 4 |
| Reentry Vehicle | 2,436 | 276 |
| Logistics Module | 345 | 53 |
| Launch Vehicles | 854 | 459 |
| Operations | 876 | 1,101 |
| Total | $7,036 | $1,893 |

Table 9.3-3: 1985 $L_1$ LIBRATION CENTER MISSION

Mission Vehicle Relative Cost Number
Basic System--With No Redundancy or Spares

| | Development | Hardware | Operation | Total |
|---|---|---|---|---|
| SUBSYSTEMS | | | | |
| Life Support System | 0.104 | 0.002 | | 0.106 |
| Communications | 0.053 | 0.001 | | 0.054 |
| Crew System | 0.006 | 0.001 | | 0.007 |
| Navigation and Guidance | 0.017 | 0.001 | | 0.018 |
| Data Management | 0.007 | 0.001 | | 0.008 |
| Electrical Power | 0.036 | 0.007 | | 0.043 |
| Extravehicular Activity | 0.031 | 0.002 | | 0.033 |
| Inflight Test | 0.001 | Negligible | | 0.001 |
| Maintenance Equipment | 0.001 | Negligible | | 0.001 |
| Propulsion | 0.040 | 0.001 | | 0.041 |
| Rendezvous and Docking | 0.006 | 0.001 | | 0.007 |
| Stability and Control | 0.086 | 0.002 | | 0.088 |
| Structure | 0.079 | 0.012 | | 0.091 |
| AGE | 0.056 | | 0.004 | 0.060 |
| TEST DEMONSTRATION | 0.092 | | | 0.092 |
| SOFTWARE | | | | |
| Computer Programming | Negligible | | Negligible | Negligible |
| Training Equipment | 0.002 | | Negligible | 0.002 |
| Simulation Equipment | 0.004 | | 0.001 | 0.005 |
| Training | Negligible | | Negligible | Negligible |
| Technical Data | Negligible | | Negligible | Negligible |
| LAUNCH SITE SUPPORT | 0.037 | ____ | 0.002 | 0.039 |
| Total | 0.658 | 0.031 | 0.007 | 0.696 |

Table 9.3-4 shows the mission vehicle relative cost numbers for a maintainable system with selected redundancies (Degree "2" maintenance) for a 180-day resupply interval. The total relative cost figures given for the items listed on Tables 9.3-3 and 9.3-4 can be directly associated with the total initial cost for the mission vehicle given in Table 9.3-1, and the total relative cost number of 1.00 can be equated to the initial cost dollars shown for the mission vehicle.

Table 9.3-5 shows the mission vehicle relative cost for a maintainable system with selected redundancies for a 360-day resupply interval, and can be directly associated with the total initial cost for the mission vehicle given in Table 9.3-2.

## 9.4 1975 MARS/VENUS FLYBY MISSION

### 9.4.1 TOTAL SYSTEMS PROGRAM COST

The total systems program cost (dollars in millions) is shown in Table 9.4-1. The initial cost category includes the total estimated costs required to achieve this mission operation, which are categorized as follows:

A) Mission vehicle equal to 1.00 and further broken down in Table 9.4-3. The mission vehicle costs include:

   1) Development

      a) Subsystem developmental costs including AGE development.

      b) Estimated flight test demonstration including one spare mission vehicle.

      c) Development of software and launch site support.

   2) Hardware--One mission vehicle estimated by subsystem.

   3) Operation--Operational set of AGE and associated sustaining effort for the software and launch site support.

B) Reentry Vehicle includes:

   1) Basic developmental costs to obtain a six-man vehicle.

   2) Flight test demonstration to accomplish a qualified system.

   3) Development of associated AGE and an operational set.

   4) Costs for the initial operational reentry vehicle.

   5) System and subsystem integration.

C) Tankers--Consist of modified S-IVB tanker modules.

D) Launch Vehicles

   1) Flight test vehicles as required to obtain a qualified reentry and mission vehicle.

   2) Launch vehicles required to achieve initial mission operation.

Table 9.3-4: 1985 $L_1$ LIBRATION CENTER MISSION

Mission Vehicle Relative Cost Number
Maintainable System--Degree "2" Maintenance (180-Day Resupply Interval)

| | Development | Hardware | Operation | Total |
|---|---|---|---|---|
| SUBSYSTEMS | | | | |
| Life Support System | 0.161 | 0.004 | | 0.165 |
| Communications | 0.082 | 0.003 | | 0.085 |
| Crew System | 0.010 | 0.001 | | 0.011 |
| Navigation and Guidance | 0.026 | 0.003 | | 0.029 |
| Data Management | 0.010 | 0.002 | | 0.012 |
| Electrical Power | 0.054 | 0.012 | | 0.066 |
| Extravehicular Activity | 0.049 | 0.002 | | 0.051 |
| Inflight Test | 0.002 | Negligible | | 0.002 |
| Maintenance Equipment | 0.001 | Negligible | | 0.001 |
| Propulsion | 0.062 | 0.001 | | 0.063 |
| Rendezvous and Docking | 0.010 | 0.001 | | 0.011 |
| Stability and Control | 0.132 | 0.005 | | 0.137 |
| Structure | 0.123 | 0.012 | | 0.135 |
| AGE | 0.087 | | 0.007 | 0.094 |
| TEST DEMONSTRATION | 0.092 | | | 0.092 |
| SOFTWARE | | | | |
| Computer Programming | Negligible | | Negligible | Negligible |
| Training Equipment | 0.002 | | Negligible | 0.002 |
| Simulation Equipment | 0.004 | | 0.001 | 0.005 |
| Training | Negligible | | Negligible | Negligible |
| Technical Data | Negligible | | Negligible | Negligible |
| LAUNCH SITE SUPPORT | 0.037 | ——— | 0.002 | 0.039 |
| Total | 0.944 | 0.046 | 0.010 | 1.000 |

Table 9.3-5: 1985 $L_1$ LIBRATION CENTER MISSION

Mission Vehicle Relative Cost Number
Maintainable System--Degree "2" Maintenance (360-Day Resupply Interval)

| | Development | Hardware | Operation | Total |
|---|---|---|---|---|
| SUBSYSTEMS | | | | |
| Life Support System | 0.161 | 0.004 | | 0.165 |
| Communications | 0.082 | 0.003 | | 0.085 |
| Crew System | 0.010 | 0.001 | | 0.011 |
| Navigation and Guidance | 0.026 | 0.003 | | 0.029 |
| Data Management | 0.010 | 0.002 | | 0.012 |
| Electrical Power | 0.054 | 0.013 | | 0.067 |
| Extravehicular Activity | 0.049 | 0.002 | | 0.051 |
| Inflight Test | 0.002 | Negligible | | 0.002 |
| Maintenance Equipment | 0.001 | Negligible | | 0.001 |
| Propulsion | 0.062 | 0.001 | | 0.063 |
| Rendezvous and Docking | 0.010 | 0.002 | | 0.012 |
| Stability and Control | 0.132 | 0.006 | | 0.138 |
| Structure | 0.123 | 0.012 | | 0.135 |
| AGE | 0.087 | | 0.007 | 0.094 |
| TEST DEMONSTRATION | 0.092 | | | 0.092 |
| SOFTWARE | | | | |
| Computer Programming | Negligible | | Negligible | Negligible |
| Training Equipment | 0.002 | | Negligible | 0.002 |
| Simulation Equipment | 0.004 | | 0.001 | 0.005 |
| Training | Negligible | | Negligible | Negligible |
| Technical Data | Negligible | | Negligible | Negligible |
| LAUNCH SITE SUPPORT | 0.037 | ——— | 0.002 | 0.039 |
| Total | 0.944 | 0.049 | 0.010 | 1.003 |

E. Operations

1) Operations for the flight test demonstration.

2) Downrange tracking and data acquisition costs accumulated during the test demonstration and operational mission.

3) Recovery operation for the mission.

### 9.4.2 MISSION VEHICLE RELATIVE COST NUMBERS

Table 9.4-2 shows the mission vehicle relative cost numbers for the basic system (with no redundancy or spares) by subsystems, AGE and spares, test demonstration, software, and launch site support. The total relative cost number includes the development, unit hardware, and operations required to obtain a mission vehicle with no redundancy or spares, and is given here only to represent the baseline system before adding a realistic spared system.

Table 9.4-3 shows the mission vehicle relative cost numbers for a maintainable system with selected redundancies (Degree 2 maintenance). The total relative cost numbers given for the items listed on Tables 9.4-2 and 9.4-3 can be directly associated with the total initial cost for the mission vehicle given in Table 9.4-1, and the total relative cost number of 1.00 can be equated to the initial cost dollars shown for the mission vehicle.

Table 9.4-4 shows the mission vehicle relative cost for a redundant system, as discussed in Section 4.2 and the appendix.

## 9.5 MARS LANDING MISSION

### 9.5.1 TOTAL SYSTEMS PROGRAM COST

The total systems program cost (dollars in millions) is shown in Table 9.5-1. The initial cost category includes the total estimated costs required to achieve this mission operation, which are categorized as follows:

A) Mission vehicle equal to 1.00 and further broken down in Table 9.5-3. The mission vehicle costs include:

1) Development

a) Subsystem developmental costs including AGE development.

b) Estimated flight test demonstration including one spare mission vehicle.

c) Development of software and launch site support.

2) Hardware---One mission vehicle estimated by subsystem.

3) Operation---Operational set of AGE and associated sustaining effort for the software and launch site support.

B) Reentry vehicle includes:

1) Basic developmental costs to obtain an eight-man vehicle with reentry cone.

Table 9.4-1: 1975 MARS/VENUS FLYBY MISSION

Total Systems Cost
(Dollars in Millions)

| | Initial |
|---|---|
| Mission Vehicle | $3,198 |
| Reentry Vehicle | 2,145 |
| Tankers | 218 |
| Launch Vehicles | 1,374 |
| Operations | 1,578 |
| Total | $8,513 |

Table 9.4-2: 1975 MARS/VENUS FLYBY MISSION

Mission Vehicle Relative Cost Number
Basic System---With No Redundancy or Spares

| | Development | Hardware | Operation | Total |
|---|---|---|---|---|
| SUBSYSTEMS | | | | |
| Life Support System | 0.095 | 0.002 | | 0.097 |
| Communications | 0.128 | 0.001 | | 0.129 |
| Crew System | 0.011 | 0.001 | | 0.012 |
| Data Management | 0.023 | 0.001 | | 0.024 |
| Electrical Power | 0.027 | 0.002 | | 0.029 |
| Extravehicular Activity | 0.024 | 0.002 | | 0.026 |
| Inflight Test | 0.001 | Negligible | | 0.001 |
| Maintenance Equipment | 0.001 | Negligible | | 0.001 |
| Propulsion | 0.076 | 0.002 | | 0.078 |
| Navigation and Guidance | 0.021 | 0.001 | | 0.022 |
| Stability and Control | 0.013 | Negligible | | 0.013 |
| Structure | 0.048 | 0.007 | | 0.055 |
| AGE | 0.056 | | 0.003 | 0.059 |
| TEST DEMONSTRATION | 0.096 | | | 0.096 |
| SOFTWARE | | | | |
| Computer Programming | Negligible | | Negligible | Negligible |
| Training Equipment | 0.002 | | Negligible | 0.002 |
| Simulation Equipment | 0.003 | | Negligible | 0.003 |
| Training | Negligible | | Negligible | Negligible |
| Technical Data | Negligible | | Negligible | Negligible |
| LAUNCH SITE SUPPORT | 0.037 | | 0.002 | 0.039 |
| Total | 0.662 | 0.019 | 0.005 | 0.686 |

Table 9.4-3: 1975 MARS/VENUS FLYBY MISSION

Mission Vehicle Relative Cost Number
Maintainable System---Degree "2" Maintenance

| | Development | Hardware | Operation | Total |
|---|---|---|---|---|
| SUBSYSTEMS | | | | |
| Life Support System | 0.148 | 0.004 | | 0.152 |
| Communications | 0.198 | 0.004 | | 0.202 |
| Crew System | 0.017 | 0.001 | | 0.018 |
| Data Management | 0.035 | 0.005 | | 0.040 |
| Electrical Power | 0.043 | 0.004 | | 0.047 |
| Extravehicular Activity | 0.037 | 0.002 | | 0.039 |
| Inflight Test | 0.001 | Negligible | | 0.001 |
| Maintenance Equipment | 0.001 | Negligible | | 0.001 |
| Propulsion | 0.117 | 0.003 | | 0.120 |
| Navigation and Guidance | 0.032 | 0.008 | | 0.040 |
| Stability and Control | 0.019 | 0.006 | | 0.025 |
| Structure | 0.075 | 0.008 | | 0.083 |
| AGE | 0.087 | | 0.004 | 0.091 |
| TEST DEMONSTRATION | 0.097 | | | 0.097 |
| SOFTWARE | | | | |
| Computer Programming | Negligible | | Negligible | Negligible |
| Training Equipment | 0.002 | | Negligible | 0.002 |
| Simulation Equipment | 0.003 | | Negligible | 0.003 |
| Training | Negligible | | Negligible | Negligible |
| Technical Data | Negligible | | Negligible | Negligible |
| LAUNCH SITE SUPPORT | 0.037 | | 0.002 | 0.039 |
| Total | 0.949 | 0.045 | 0.006 | 1.000 |

Table 9.4-4: 1975 MARS/VENUS FLYBY MISSION

Mission Vehicle Relative Cost Number
Redundant System---Degree 0 Maintenance

| | Development | Hardware | Operation | Total |
|---|---|---|---|---|
| SUBSYSTEMS | | | | |
| Life Support System | 0.172 | 0.006 | | 0.178 |
| Communications | 0.230 | 0.005 | | 0.235 |
| Crew System | 0.019 | 0.002 | | 0.021 |
| Data Management | 0.040 | 0.010 | | 0.050 |
| Electrical Power | 0.050 | 0.007 | | 0.057 |
| Extravehicular Activity | 0.043 | 0.005 | | 0.048 |
| Inflight Test | 0.002 | Negligible | | 0.002 |
| Maintenance Equipment | 0.001 | Negligible | | 0.001 |
| Propulsion | 0.156 | 0.004 | | 0.140 |
| Navigation and Guidance | 0.038 | 0.008 | | 0.046 |
| Stability and Control | 0.022 | 0.007 | | 0.029 |
| Structure | 0.087 | 0.008 | | 0.095 |
| AGE | 0.101 | | 0.005 | 0.106 |
| TEST DEMONSTRATION | 0.097 | | | 0.097 |
| SOFTWARE | | | | |
| Computer Programming | Negligible | | Negligible | Negligible |
| Training Equipment | 0.002 | | Negligible | 0.002 |
| Simulation Equipment | 0.003 | | Negligible | 0.003 |
| Training | Negligible | | Negligible | Negligible |
| Technical Data | Negligible | | Negligible | Negligible |
| LAUNCH SITE SUPPORT | 0.037 | ——— | 0.002 | 0.039 |
| Total | 1.080 | 0.062 | 0.007 | 1.149 |

2) Flight test demonstration to accomplish a qualified system.

3) Development of associated AGE and an operational set.

4) Costs for the initial operational reentry vehicle.

5) System and subsystem integration.

C) Propulsion Modules---Consist of the propulsion modules as outlined in the Integrated Manned Interplanetary Spacecraft Concept Definition (IMISCD) study, Reference 86.

D) Tankers---Consist of the tanker module.

E) Launch Vehicles

1) Flight test vehicles as required to obtain a qualified reentry and mission vehicle.

2) Launch vehicles required to achieve initial mission operation.

F) Operations

1) Operations for the flight test demonstration.

2) Downrange tracking and data acquisition costs accumulated during the test demonstration and operational mission.

3) Recovery operation for the mission.

Table 9.5-1: 1985 MARS LANDING MISSION

Total Systems Cost
(Dollars in Millions)

| | Initial |
|---|---|
| Mission Vehicle | $3,438 |
| Reentry Vehicle | 2,047 |
| Propulsion Modules | 142 |
| Tankers | 145 |
| Launch Vehicles | 1,796 |
| Operations | 2,013 |
| Total | $9,581 |

9.5.2 MISSION VEHICLE RELATIVE COST NUMBERS

Table 9.5-2 shows the mission vehicle relative cost numbers for the basic system (with no redundancy or spares) by subsystems, AGE and spares, test demonstration, software, and launch site support. The total relative cost number includes the development, unit hardware, and operations required to obtain a mission vehicle with no redundancy or spares, and is given here only to represent the baseline system before adding a realistic spared system.

Table 9.5-3 shows the mission vehicle relative cost numbers for a maintainable system with selected redundancies (Degree "2" maintenance). The total relative cost numbers given for the items listed on Tables 9.5-2 and 9.5-3 can be directly associated with the total initial cost for the mission vehicle given in Table 9.5-1, and the total relative cost number of 1.00 can be equated to the initial cost dollars shown for the mission vehicle.

Table 9.5-2: 1985 MARS LANDING MISSION

Mission Vehicle Relative Cost Number
Basic System---With No Redundancy or Spares

| | Development | Hardware | Operation | Total |
|---|---|---|---|---|
| SUBSYSTEMS | | | | |
| Life Support System | 0.090 | 0.002 | | 0.092 |
| Communications | 0.051 | 0.001 | | 0.052 |
| Crew System | 0.006 | 0.001 | | 0.007 |
| Data Management | 0.005 | Negligible | | 0.005 |
| Electrical Power | 0.029 | 0.002 | | 0.031 |
| Extravehicular Activity | 0.024 | 0.002 | | 0.026 |
| Inflight Test | 0.001 | Negligible | | 0.001 |
| Maintenance Equipment | Negligible | Negligible | | Negligible |
| Propulsion | 0.071 | 0.002 | | 0.073 |
| Navigation and Guidance | 0.008 | Negligible | | 0.008 |
| Stability and Control | 0.128 | 0.003 | | 0.131 |
| Structure | 0.048 | 0.007 | | 0.055 |
| AGE | 0.055 | | 0.003 | 0.058 |
| TEST DEMONSTRATION | 0.118 | | | 0.118 |
| SOFTWARE | | | | |
| Computer Programming | Negligible | | Negligible | Negligible |
| Training Equipment | 0.002 | | Negligible | 0.002 |
| Simulation Equipment | 0.006 | | Negligible | 0.006 |
| Training | Negligible | | Negligible | Negligible |
| Technical Data | Negligible | | Negligible | Negligible |
| LAUNCH SITE SUPPORT | 0.037 | ——— | 0.002 | 0.039 |
| Total | 0.679 | 0.020 | 0.005 | 0.704 |

Table 9.5-3: 1985 MARS LANDING MISSION

Mission Vehicle Relative Cost Number
Maintainable System---Degree "2" Maintenance

| | Development | Hardware | Operation | Total |
|---|---|---|---|---|
| SUBSYSTEMS | | | | |
| Life Support System | 0.140 | 0.003 | | 0.143 |
| Communications | 0.078 | 0.003 | | 0.081 |
| Crew System | 0.009 | 0.001 | | 0.010 |
| Data Management | 0.008 | 0.002 | | 0.010 |
| Electrical Power | 0.044 | 0.004 | | 0.048 |
| Extravehicular Activity | 0.038 | 0.002 | | 0.040 |
| Inflight Test | 0.001 | Negligible | | 0.001 |
| Maintenance Equipment | 0.001 | Negligible | | 0.001 |
| Propulsion | 0.109 | 0.003 | | 0.112 |
| Navigation and Guidance | 0.012 | 0.001 | | 0.013 |
| Stability and Control | 0.198 | 0.004 | | 0.202 |
| Structure | 0.075 | 0.008 | | 0.083 |
| AGE | 0.086 | | 0.004 | 0.090 |
| TEST DEMONSTRATION | 0.118 | | | 0.118 |
| SOFTWARE | | | | |
| Computer Programming | Negligible | | Negligible | Negligible |
| Training Equipment | 0.002 | | Negligible | 0.002 |
| Simulation Equipment | 0.006 | | 0.001 | 0.007 |
| Training | Negligible | | Negligible | Negligible |
| Technical Data | Negligible | | Negligible | Negligible |
| LAUNCH SITE SUPPORT | 0.037 | ——— | 0.002 | 0.039 |
| Total | 0.962 | 0.031 | 0.007 | 1.000 |

# 10.0 AREAS REQUIRING ADDITIONAL STUDY OR TECHNICAL RESEARCH

As a part of the analysis conducted in this study, it was necessary to channel the effort into certain areas to stay within budgetary time and cost constraints. Consequently, a number of areas of interest were uncovered that could not be adequately covered in this study. Since the study investigated missions proposed for the 1975 and 1985 time periods, it was also necessary to make certain estimates and assumptions about the expected state of the art for those time periods. In many cases, additional technology research effort will be required to determine the best approach to be taken. Those areas requiring additional study or technical research have been categorized into four major headings: hardware design, methodology development, space data and environment, and maintenance procedures and techniques. In some instances, the study or research effort identified could logically be placed in more than one category. These areas are then discussed under the first applicable category and have not been repeated.

## 10.1 HARDWARE DESIGN

### 10.1.1 LIFE SUPPORT SYSTEM PACKAGING CONFIGURATIONS

The life support system imposes the greatest unscheduled and scheduled maintenance workload on the spacecraft crew. Optimum design, packaging, and layout of this system within the spacecraft are necessary to reduce this workload. A major effort in additional study and research is required to achieve this reduction.

### 10.1.2 COMMONALITY OF SPACECRAFT COMPONENTS

Maximum commonality of spacecraft components, within and between subsystems, was found to be an effective means of reducing on-board spares requirements and the maintenance workload. Reentry vehicle and experiment systems also use a large number of components that perform functions common to other spacecraft equipment. Additional study is required to make a detailed investigation of the components used in a space mission and to determine what components can be designed for realistically common usage.

### 10.1.3 COMMONALITY OF EXPERIMENT COMPONENTS

Equipment used for experiments should be considered not only for intraexperiment commonality, but also for commonality with components in other subsystems of the mission vehicle. This would provide an additional source of spares, allow more effective use of the spares provisioned on-board, and permit a reduction in total spares requirements. In addition, if the experiments require an on-board workshop, the use of Degree "3" maintenance for both experiment and subsystem support becomes increasingly effective and its justification is considerably stronger.

### 10.1.4 MODULARIZATION

Modularization of relatively high-failure-rate equipment was determined to be an effective way to reduce spares weight requirements. Additional research is required to identify the most effective technique of modularizing different types of equipment to obtain the maximum benefits to the spares concept.

### 10.1.5 EXTERNAL LSS PLUG-IN RECEPTACLES

The feasibility of providing external plug-in receptacles that could be used to operate spacesuits from the spacecraft life support system instead of the backpack should be investigated. Supplying the spacesuit requirements directly from the spacecraft life support system would extend the length of time an astronaut could be outside the spacecraft. It could also result in a saving in weight because of the water and oxygen that is lost during backpack operation and must be provided for in the initial supplies and resupplied for the Earth-orbit missions.

### 10.1.6 STRUCTURE LEAK DETECTION AND REPAIR

Structural repair was assumed for both mission time periods, but it is not clear what methods, techniques, and tools will be required to accomplish it. The major structural repair task is assumed to be sealing of the pressure hull. In the available literature reviewed, it appeared that repair from within was generally assumed. It is felt that repair from outside should be strongly considered. Repair from within poses the problem of locating the puncture or leak and reaching it through the equipment stacked against the hull. The interior equipment could be placed away from the hull, but this is volumetrically inefficient and eliminates the radiation protection provided by hull-mounted equipment. Repair from the exterior could be hampered by meteoroid shielding, but this depends on the design of the shielding. The exterior repair offers the advantages of easy access to the puncture and relative ease of location by visual observation (of frosting or vapor indications as well as damage), and by ionization gages or sonic detectors (Reference 89). The hardest breaches to locate are expected to be the slow leaks, and these will be extremely difficult to locate from the interior. Interior patching capability might be limited to emergency patches to seal large meteoroid punctures. It is recommended that the general field of structural repair be reviewed and that the most promising methods of repair be investigated in detail. The techniques presented in Reference 89 are among those that might be subjected to a test by practical application.

### 10.1.7 FILAMENT-WOUND TANKS

The use of filament-wound storage tanks for fluid was assumed for the 1985 mission at a considerable saving in weight. This technology should be researched further so the benefits can be used as soon as possible (such as for the 1975 missions).

### 10.1.8 TANK REPAIR

Tank repair should be investigated in conjunction with Items 10.1.6 and 10.1.7. The failure modes of various types and sizes of tanks should be identified and the possibility of repair assessed considering the failure mode, type of material, pressure, and tank contents. It is conceivable that some tankage can be patched before the tank contents are lost, assuming timely detection of the failure.

### 10.1.9 EMERGENCY ELECTRICAL POWER SOURCE

The use of an isotope fuel invites the investigation of an interesting method of generating emergency power. It should be possible to incorporate thermocouples in the fuel block or in the block shield to provide emergency electrical power for the spacecraft. The power generated would be low level, but adequate to provide minimum lighting and control power until the main power system is restored to operation.

### 10.1.10 RADIATION SHIELDING FROM EXPENDABLES

Considerable radiation shielding weight could be saved by judicious placement of spares, food, other expendables, and waste products. A study should be made to determine practical methods of storing these items to obtain maximum shielding benefits while permitting access for easy removal and/or storage.

### 10.1.11 REFURBISHMENT OF REENTRY VEHICLES

A long-duration mission with periodic resupply requires the use of a considerable number of reentry vehicles. It is believed the total cost of the mission could be reduced substantially if the command module were designed for refurbishment and subsequent reuse.

### 10.1.12 VACUUM SYSTEM FOR MAINTENANCE

One of the items of maintenance equipment postulated in this study is a vacuum system to be used in controlling debris or fluids while performing maintenance. Different vacuum devices should be evaluated to arrive at the optimum procedures and equipment to control the variation in conditions that could be encountered.

### 10.1.13 BATTERY AND ENGINE WEAROUT LIFE

The expected life for the batteries and reaction control engines was estimated to be one year for the 1975 time period. This resulted in a considerable scheduled maintenance workload being imposed on the mission. Improvements in the expected life of equipment such as this will result in substantial reductions of the workload.

### 10.1.14 ISOTOPE FUEL SOURCE RECOVERY

The optimum method for recovery of the fuel block for those missions using a Pu-238 heat source needs to be determined. There are several methods of

recovery described in the available literature on isotope-fueled space power systems. However, all have some operational or design problem that makes selection of the superior method difficult. In this study, weight was allocated to the recovery system, but the exact method was not defined.

## 10.2 METHODOLOGY DEVELOPMENT

The area of space mission analysis and optimization has a number of deficient areas that should be improved. Refined mission planning requires determination of definitive and valid optimization criteria, development of a better data base to enable accurate total mission planning, construction of more versatile mission risk and probability models, and the availability of better optimization techniques.

### 10.2.1 ESTABLISHING VALID OPTIMIZATION CRITERIA

General optimization models can consider any set of pertinent variables in making an optimal selection. Unfortunately, determination of what variables are pertinent and what the weighting of these variables should be is beyond the scope of any optimization model. Such judgments must be based on man's assessment of the political, economic, and risk effects of the variables in relation to the mission objective. Minimum dollar cost for a fixed degree is a desirable objective, but it is a difficult one to grasp because of the intricacies of the costing required. For example, low-cost additions may cause an inappropriate weight increase resulting in much higher launch costs and a net increase in total mission cost. Methods that go beyond the present parametric techniques must be developed.

### 10.2.2 DATA DEFICIENCIES

All of the analysis models discussed above thrive on data; in fact, the accuracy of the results derived depends on the accuracy of the data available. This is the reason that this study went to as great a depth as possible to define missions and mission hardware. It was found in accumulating data for this study that such information is not readily obtained from a single source. It would be of great value to future studies to compile, in some form, a data bank of detailed information about space systems, subsystems, boosters, launch and launch support systems, etc. Such a data bank should contain cost ranges, state-of-the-art information, expected state-of-the-art improvements, and other necessary variables.

### 10.2.3 MISSION RISK DETERMINATION

It is found that mission risk is more complex than a simple component reliability problem. Factors such as orbital assembly, abort after injection, branch excursions such as the Mars lander, and discrete mission events such as "kick" stage operation for the Mars flyby mission are related in a complex manner to the total mission risk (if such an expression actually exists). If a mission profile is known, and all the necessary probabilities are known, a risk model can be constructed for a specific mission. What is not presently available is

a general model into which mission profiles and parameters can be placed to optimize alternate concepts and compare different mission profiles.

### 10.2.4 OPTIMIZATION MODEL DEFICIENCIES

The MARCEP technique used in this study is one of the most advanced optimization models available, and yet it has a number of "soft" areas which should be improved.

1) One area is in the ability of the model to handle structural elements. Under the limitations of the model, it is impossible to accurately add structural and tank redundancy weight, which is a necessity if repair by kit cannot logically be accomplished.

2) Another area is in the field of standby redundancy, or more accurately, the "neo-spare" area, where one standby item can be switched in to replace any one of several similar items. MARCEP standby redundancy is by cell only: one basic component, one standby; two basic, two standby; etc. This is realistic in many cases, particularly for mechanical items, but for electrical items it is somewhat deficient.

3) Missing also is an algorithm for assessing additional structure, development cost, training costs, power drain, tools, packing material, storage volume and weight, etc., required to accomplish parallel, standby, or spares additions over and above the incremental dollar, weight, volume, and repair time penalties now assessed.

4) Also missing is the ability to consider and trade alternate design approaches for a function in a single optimization process.

## 10.3 SPACE DATA AND ENVIRONMENT

### 10.3.1 LONG-TERM EFFECTS OF SPACE ENVIRONMENT

The long-term effects of space environment factors on the life and operation of spacecraft equipment need to be defined. For example, the effects of radiation, micrometeoroids, magnetic fields, cosmic rays, orbit perturbation (gravity), etc., were not evaluated or were given only cursory consideration in this study. The long-term effects of the space environment on the shelf life of spares in storage also need to be defined. It may be necessary to rotate or recycle some of the spares due to shelf-life degradation. Crew members are rotated periodically to limit the radiation dose received, but if the same problem exists with equipment, it needs to be identified.

### 10.3.2 HUMAN PERFORMANCE IN SPACE ENVIRONMENT

There is a need for further quantification of human performance in the space environment. Until this is done, all design criteria and mission planning will be based on limited data that is insufficient to safely perform the mission goals. The precise capabilities and limitations of man in the space environment must be further tested to the extent of performing a wide variety of maintenance tasks in pressurized suits, under conditions of simulated maintenance, work space, lighting, and restraint. The crew performance reliability needs to

be predicted in order to determine the extent to which the system must be designed to either compensate for the crew's limitations or to take advantage of their capabilities.

### 10.3.3 SPACECRAFT LEAKAGE RATES

For purposes of this study, the spacecraft leakage rate assumed was 2.0 pounds per day (per Reference 1). Boeing studies indicate that this is overly optimistic and that 5.0 pounds per day would be more realistic, especially for the 1975 time period. Additional research is required in this area to establish and validate a realistic leakage rate for various spacecraft structure configurations.

## 10.4 MAINTENANCE PROCEDURES AND TECHNIQUES

### 10.4.1 ANTICIPATORY MALFUNCTION DETECTION

The data from this study indicates relatively short time periods required for unscheduled maintenance. It also indicates average scheduled maintenance exceeds unscheduled maintenance by a large factor. However, both scheduled and unscheduled maintenance frequency and duration requirements may still be greatly decreased by the application of improved anticipatory malfunction detection and checkout techniques. Further study effort is needed to determine these techniques and their probable impact upon maintenance considerations for long-duration manned space flight.

Scheduled maintenance is primarily based on trend analyses, which historically have been pessimistic. If component failure can be more accurately predicted or impending failure precisely detected, scheduled maintenance may be performed only when necessary on those components that would eventually require unscheduled maintenance. This would tend to maintain the integrity of the subsystem, and require less crew time and fewer spares. Maintenance to avert the detected impending failure could be performed within a span of time at the convenience of the crew. In effect, this would amount to only scheduled maintenance, with unscheduled maintenance being eliminated.

Several possibilities for meeting the need for anticipatory malfunction detection are being developed at the present time. These techniques include X ray, electromicroscope, infrared screening, and analysis of generated noise. With the exception of the generated-noise technique, and possibly the infrared screening, the techniques listed appear to be too costly for the immediate future and require additional crew training to use. While a component is operating within specifications, the existence of a detectable defect will change the character of the noise spectrum or signature of the equipment. The analysis of the noise signature will lead to the detection of incipient failure in the equipment. Both acoustic and vibration transducers could be employed for mechanical components. The evaluation of electronic noise has been an accepted technique already used to determine the quality of components, to measure radio frequency interference, to detect and protect against transients, and as a troubleshooting tool. The use of noise monitoring to detect incipient failures must be further studied in regard to reducing maintenance tasks.



VERTICAL TYPING FORMAT (UNCLASSIFIED)

### 10.4.2 BUILT-IN TEST EQUIPMENT

Another method for reducing maintenance time, independent from the technique of anticipatory maintenance, is that of built-in test equipment (BITE). The failure of many of the vehicle components will require their immediate repair; however, troubleshooting techniques are often time consuming. The BITE concept would provide a means of sensing faults and providing indication of the condition of the equipment being monitored, either in the vicinity of the failure or at a single monitoring source, as appropriate. This would eliminate the need for auxiliary external test devices to perform checks and would provide a continuous monitor of system performance during the mission. Trade studies need to be conducted on the use of the BITE concept as opposed to the use of external test equipment, which implies the need for crew skills and training to operate the test equipment.

### 10.4.3 MAINTENANCE TECHNIQUES AND SPARES CONCEPTS FOR LARGE ASSEMBLIES

Large assemblies such as radiators, tanks, airlocks, or equipment for which adequate detail was not available (such as reentry vehicles, experiments, probes, powered locomotion devices, etc.) were all assumed to be repaired by a special maintenance or repair kit. Because of inadequate details available, it was necessary in this study to assume an average weight and volume required to repair a failure of one of these items. Additional study is required in these areas to determine the best techniques for repair of this equipment and the resulting effect on the spares requirements.

### 10.4.4 HANDLING LARGE EQUIPMENT

Handling of large items of equipment that require two men and coordination of their actions could present problems in a zero-g environment and needs to be researched.

### 10.4.5 REPAIR OF LARGE EQUIPMENT

There is a need to investigate the area of space radiator repair, large tank repair, antenna repair, solar cell repair, and repair of similar large items for which it is not practical to use a total "remove and replace" concept. The use of equipment such as electron-beam welders, fusion joining processes, and other possible techniques should be evaluated.

### 10.4.6 EVA ENVIRONMENT

There may be problems associated with EVA performed under extreme variations in light contrasts, light intensities, and temperatures. Techniques for coping with these conditions should be studied.

### 10.4.7 SPACECRAFT HAZARDS TO EXTRAVEHICULAR MOVEMENT

It is anticipated that solar arrays, antennas, external experiments, and experiment booms will present a hazard to EVA and to rendezvous and docking maneuvers. Similarly, EVA and resupply-vehicle maneuvering will present a

hazard to solar panels and other appendages. The magnitude of these hazards should be assessed and procedures and equipment should be developed to minimize the hazards.

### 10.4.8 SPACECRAFT-EVA TRANSITION PROCEDURES

For maintenance involving EVA, the time required in making the transition from a shirtsleeve environment to the external space environment should be evaluated in detail to establish techniques by which a reduction can be accomplished in the time required for prebreathing pure oxygen, donning and checkout of spacesuit equipment, egress and ingress through an airlock, etc.

### 10.4.9 HANDLING FLUIDS IN ZERO-G ENVIRONMENT

Procedures and techniques for handling fluids in zero-gravity environment during servicing and maintenance activities need to be established and evaluated under actual space-flight conditions. These activities are basic to maintenance of manned systems and should be included early in any space experiment program.

### 10.4.10 CARRYING EQUIPMENT AND SPARES

Carrying maintenance equipment and spares that are too large for a tool kit or for a garment pocket may also present problems in zero-g during both exterior and interior maintenance. Methods of carrying such items need to be evaluated under actual space conditions.

### 10.4.11 DEGREE "3" (REMOVE AND REPAIR) MAINTENANCE

This concept should be studied in more detail to determine specifically when it may be economical and what workshop facilities and crew skills are required. For some of the subsystems, it might be possible to justify a limited bench-level repair capability, but this needs to be studied more thoroughly.

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# Appendix I

## SUBSYSTEM LEVEL MAINTENANCE CONCEPT COMPARISON

# Appendix I

## SUBSYSTEM LEVEL MAINTENANCE CONCEPT COMPARISON

Investigation into the effects of maintenance concept selection were conducted on the subsystem level because it was recognized that a gross system-level maintenance concept would be meaningless or very difficult to define in practical terms, and that working concepts could be identified more easily at the subsystem level. The figures accompanying each subsystem discussion compare weights added for each of the maintenance concepts evaluated. Other variables not apparent in the weight comparisons are discussed, and the expected mean unscheduled repair time and interval between repairs is indicated. This information was derived from simulation of the 1975 Mars flyby mission; more detail on unscheduled maintenance time for each mission is provided in Sections 5.3 and 6.3. The difference in relative cost between the Degree "0" and Degree "2" maintenance concepts is also indicated. Table 4.1.2 provides a relative cost summary for each of the maintenance concepts evaluated. Additional costing information may be found in Section 9.0.

The assurance levels used for each of the subsystems were obtained from the system level concept comparisons, where the reliability goals allocated to each subsystem were identified. Individually, these goals are necessarily higher than the 99% assurance level required of the total system.

## I.1 COMMUNICATIONS SUBSYSTEM (FIGURE I-1)

Figure I-1 shows that a Degree "2" maintenance concept results in about 100 kilograms less weight being added to the subsystem than is added for the Degree "0" maintenance concept at about 0.998 probability of assurance. The relative cost numbers found for the competitive maintenance concepts were 0.202 and 0.235 for the Degree "2" and the Degree "0" maintenance concepts, respectively. The cost and weight comparisons indicate that Degree "2" maintenance is desirable; however, the trade is so close that further study is indicated. Other factors, such as skill level required, EVA penalties, technical information requirements, etc., may ultimately determine the maintenance concept selected. From the simulation of the 1975 Mars/Venus flyby mission it was determined that the average unscheduled repair time per failure would be about 280 minutes and failures would occur approximately every 122 days. This makes the communications subsystem one of the major contributors to the total unscheduled maintenance workload. Recognizing this, and the fact that most of the maintenance actions are one-of-a-kind actions (expected to occur only once), a compromise between Degree "2" and Degree "0" maintenance is indicated. Degree "1" maintenance with deviations for selected components is the recommended choice of maintenance concept for the planetary class of missions in the 1975 time period. Further guidelines to the selection of a maintenance concept for this system are provided in Section 7.2.1.

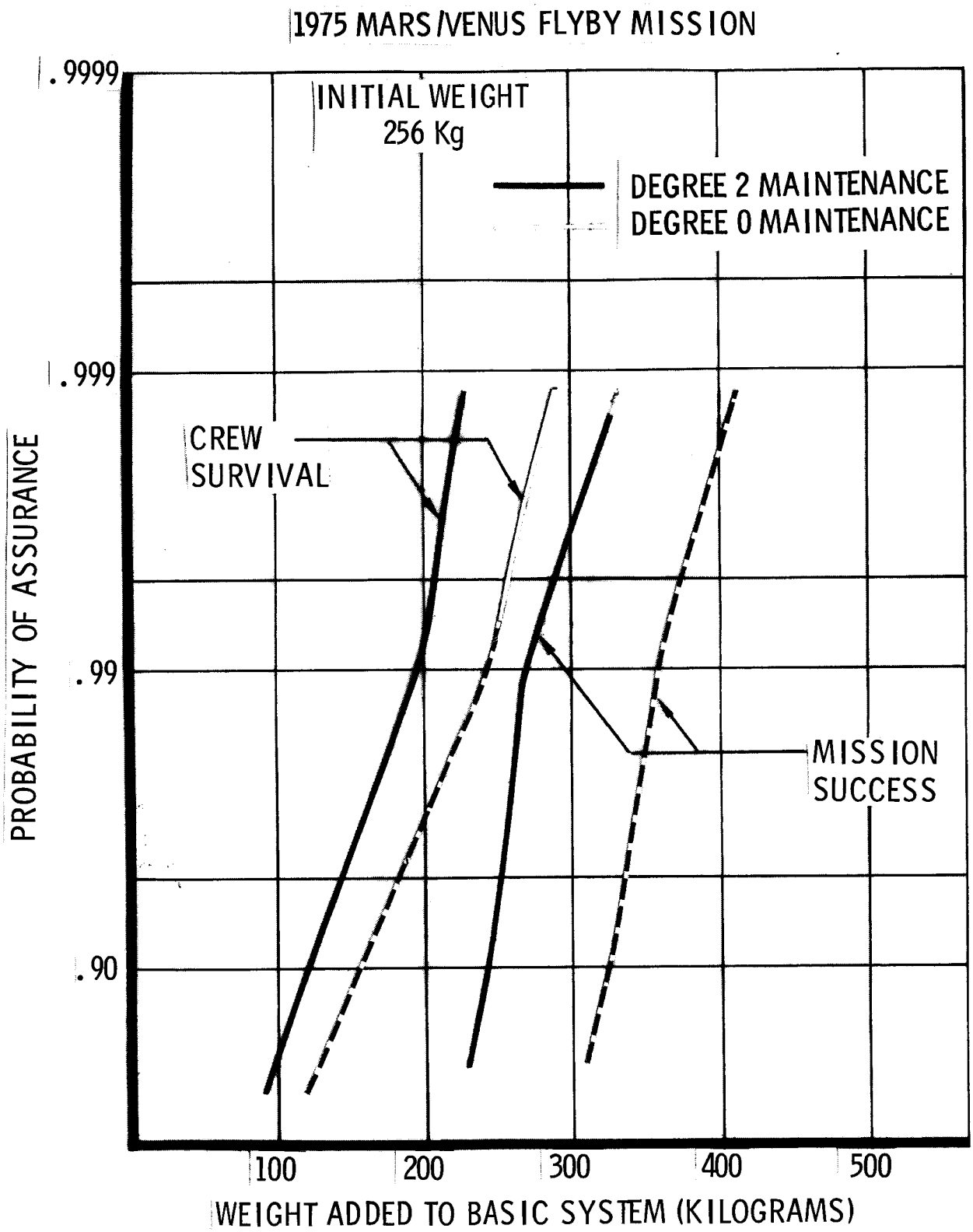



Figure I-1: MAINTENANCE CONCEPT COMPARISON — Communications Subsystem

## I.2 CREW SUBSYSTEM (FIGURE I-2)

The weight difference between the two maintenance concepts is obviously small, about 50 kilograms in favor of Degree "2" maintenance at the required level of assurance. The curves for mission success are interesting because they indicate that redefinition of an item in the system is required. The deflection in those curves at the 0.999 assurance level is caused by statistical stagnation due to reluctance of the optimization program to add an additional set of TV tapes. Finally, the entire package of tapes was added as a spare which caused a significant increase in weight added. This seems to indicate that a better approach would be to provide a small splicing kit to accomplish repairs on broken tapes. Other types of tape failure such as embrittlement, demagnetization, etc., would probably be caused by environment and would affect the spares also.

The relative cost difference was also small, 0.003 in favor of the Degree "2" concept. It would seem that Degree "0" maintenance might be seriously considered for this subsystem to reduce crew time expenditure. However, the expenditure saved would be very small. The average unscheduled repair time was determined to be 70 minutes which would occur about every 3400 days. Further, there are many items in the subsystem which cannot logically be made redundant. In toto, therefore, Degree "2" maintenance is recommended.

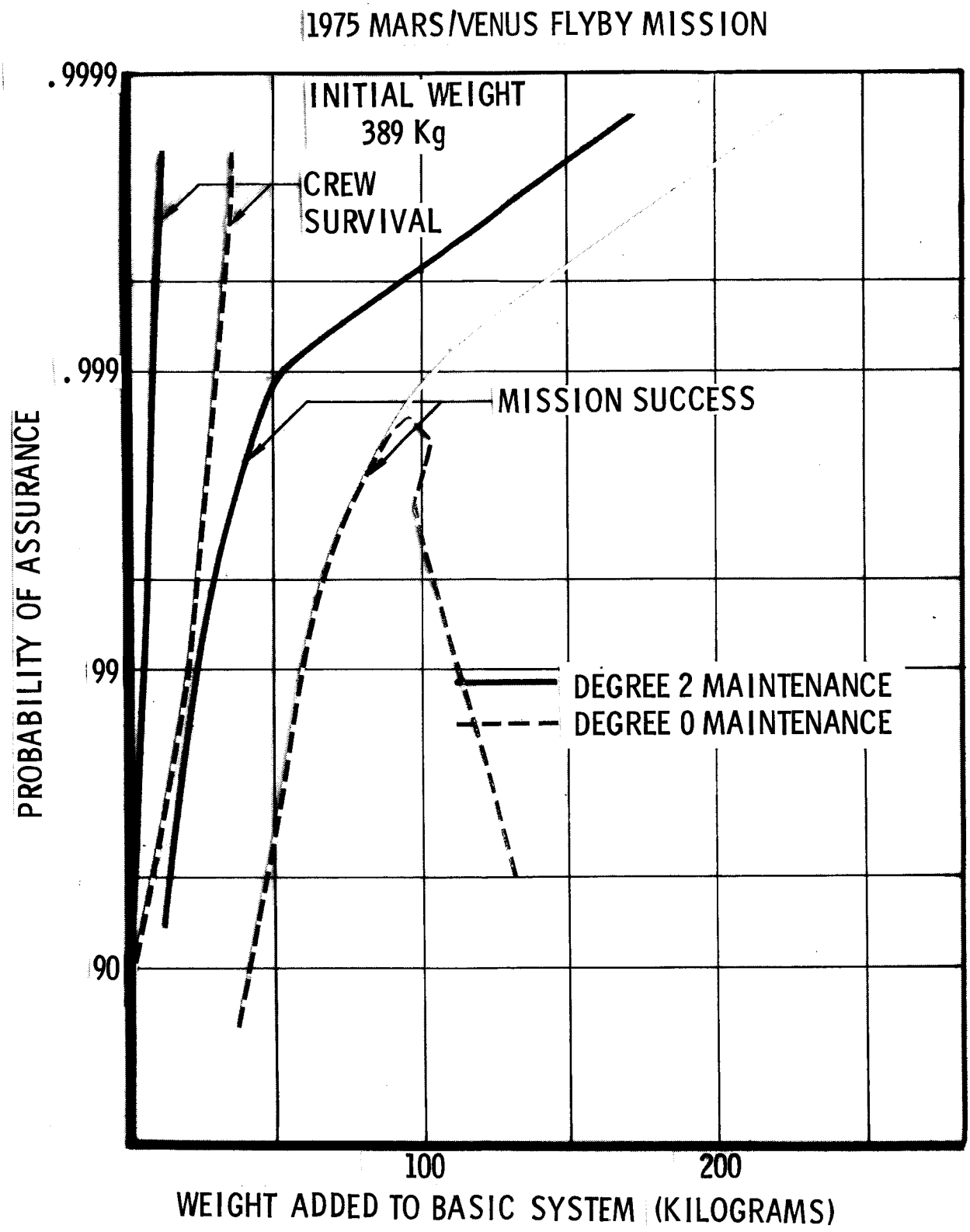



Figure I-2 MAINTENANCE CONCEPT COMPARISON — Crew System

## I.3 DATA MANAGEMENT SUBSYSTEM (FIGURE I-3)

The data management subsystem is comprised primarily of components related only to mission success. The exceptions to this are the on-board computer, and the data adapter which interfaces with the computer and other spacecraft subsystems. It is apparent, then, that the weights added for crew survival are additional computers and replaceable modules of the data adapter. The computer was not modularized in this analysis; however, the on-board computer was modularized in the 1985 missions. Three spare computers were added for crew survival and one additional for mission success. The additional spare added for mission success increases the probability of crew survival above the required 0.99 by some increment. The exact amount of the crew survival bonus was not determined because this type of event occurs a number of times in the system level analysis, and exact determination of the end probability of crew survival is beyond the scope of this study. It is sufficient to say that the 0.99 probability of crew survival requirement was met, and that when 0.99 probability of mission success is expected, the inherent crew survival probability is higher than 0.99.

The nature of the components comprising the data management subsystem and the weight penalty incurred by designing a Degree "0" maintenance subsystem indicate that Degree "2" maintenance should be planned for this subsystem. The components of this subsystem are primarily electronic in nature and could be modularized into replaceable packages or circuit boards. This also applies to most of the sensors that are part of the equipment, in particular those that are located within the pressurized mission module. Some of the sensors require redundancy---those located externally in unpressurized parts of the space vehicle or in locations highly inaccessible to a spacesuited repairman.

The relative cost difference between the competitive maintenance concepts was found to be 0.010 in favor of the Degree "2" concept. The average unscheduled repair time is expected to be 105 minutes and occurs about every 11 days.

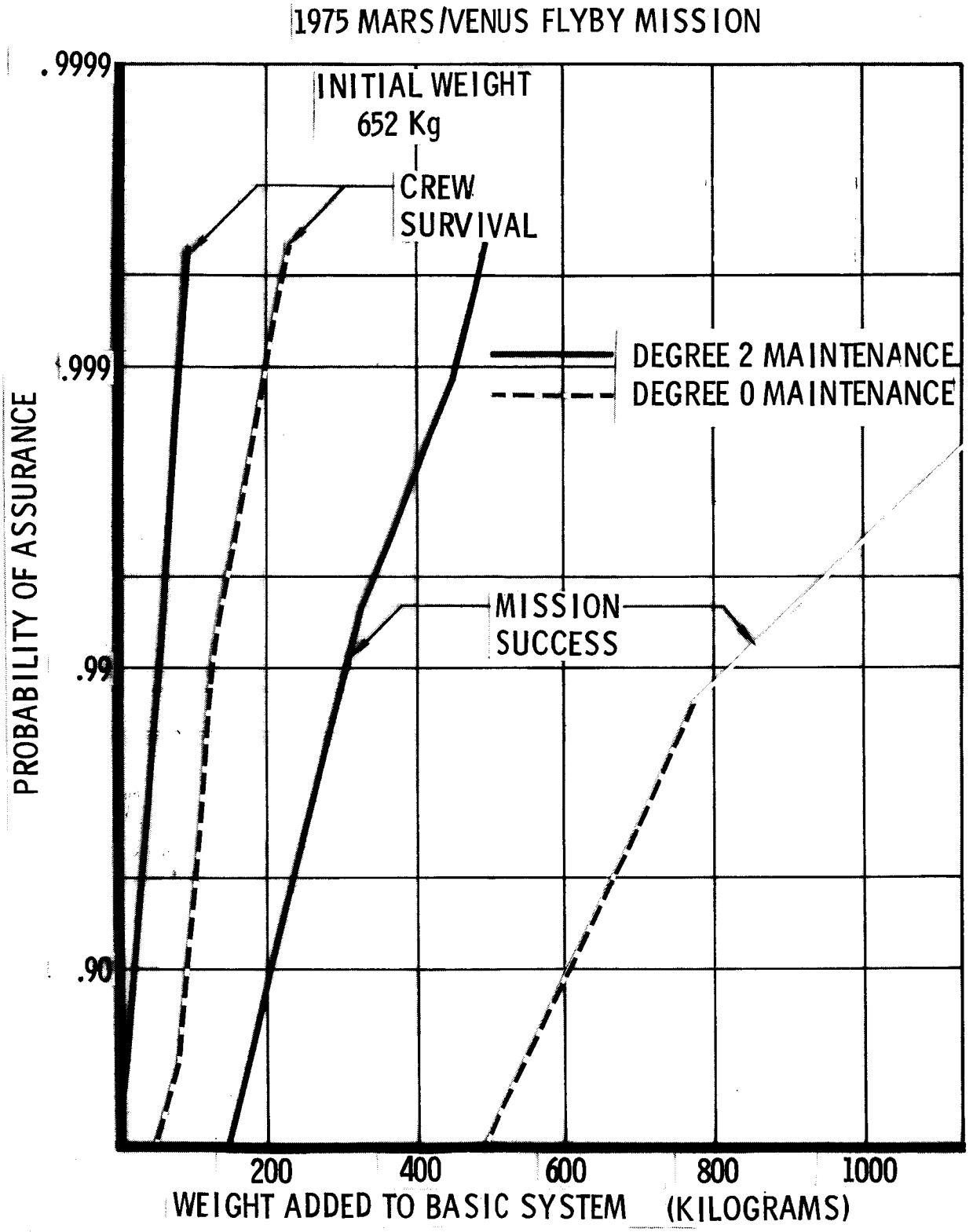



Figure I-3 MAINTENANCE CONCEPT COMPARISON — Data Management Subsystem

## I.4 ELECTRICAL POWER SUBSYSTEM (FIGURE I-4)

The electrical power subsystem is almost entirely related to crew survival. The weights of components related only to mission success were so low that mission success curves were not plotted for this subsystem. The basic subsystem required for the mission includes two independent Brayton cycle power conversion loops driven by a common isotope fuel block. Each unit produces about 5.5 kwe which is enough to sustain the necessary crew survival equipment. To prevent gross underestimation of crew survival probability, a single Brayton cycle unit was identified in the mission data. This item was coded such that at least one unit would be added in parallel redundancy. In practice this unit would operate to carry the electrical load of the mission success equipment (experiments, etc.). In the event of failure of one unit, the other operating unit would be switched to the essential bus and provide power to essential equipment until the first unit could be replaced. Therefore, the curve for the Degree "2" maintenance subsystem includes parallel redundancy of one of the heaviest components in the subsystem. After being added in parallel redundancy, as desired, one spare power conversion unit was added. Practically, this is the only choice available if reliability improvement of the unit cannot be achieved (the failure rate estimate includes improvement to the 1975 time period). Additional parallel or standby redundancy of the power conversion unit would require an additional isotope fuel source and shielding, or a major redesign of the gas loops to permit the source heat exchangers to be switched to the standby unit.

The degree of maintenance for the balance of the items in the electrical power subsystem should be determined by item. Some items could be designed into the spacecraft as standby units rather than as spares with little penalty; others are required in sufficient backup quantities to make standby redundancy undesirable.

The relative cost difference was determined to be 0.010 in favor of the Degree "2" maintenance concept. The average unscheduled repair time was found to be about 200 minutes, and repairs would occur about every 114 days.

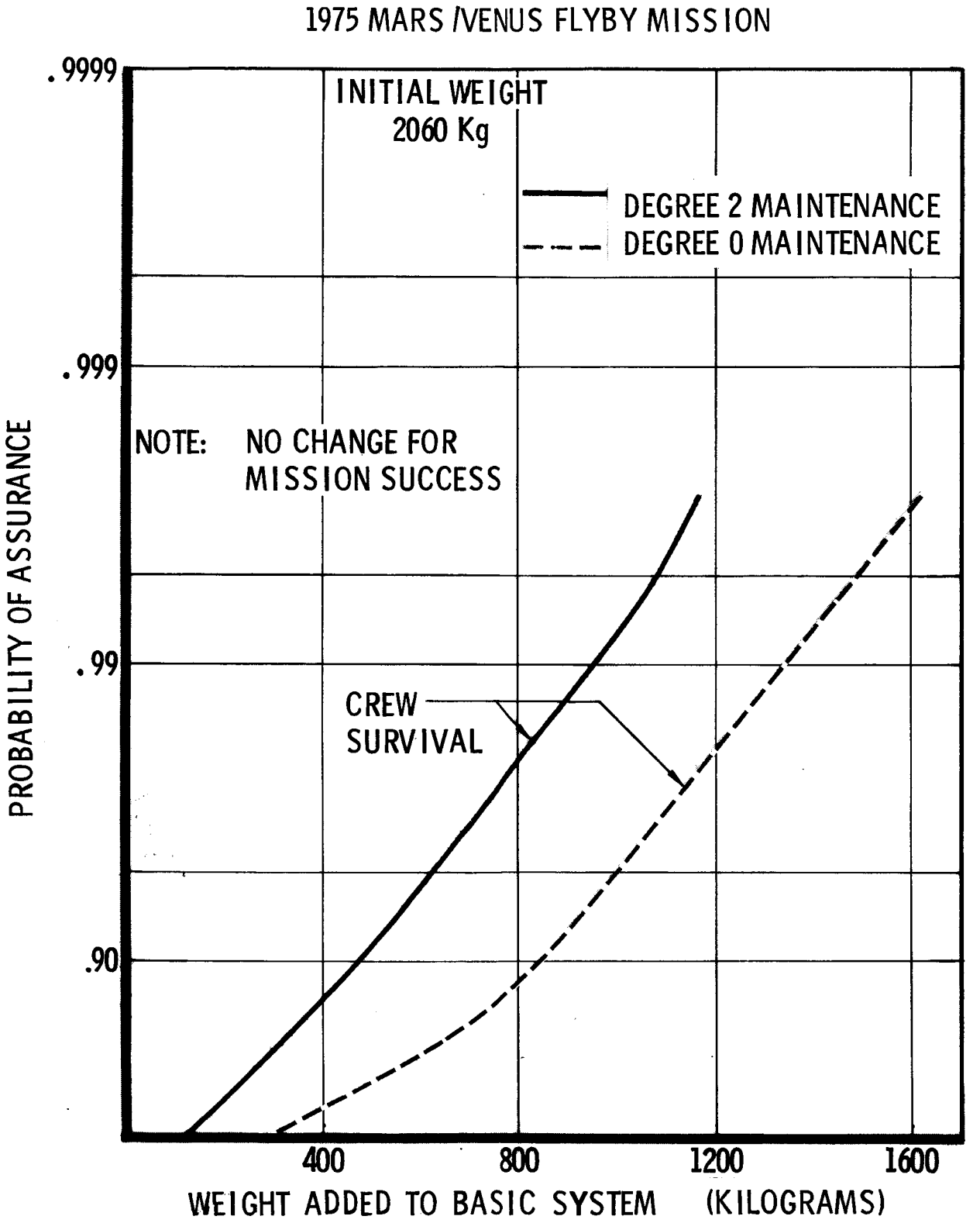
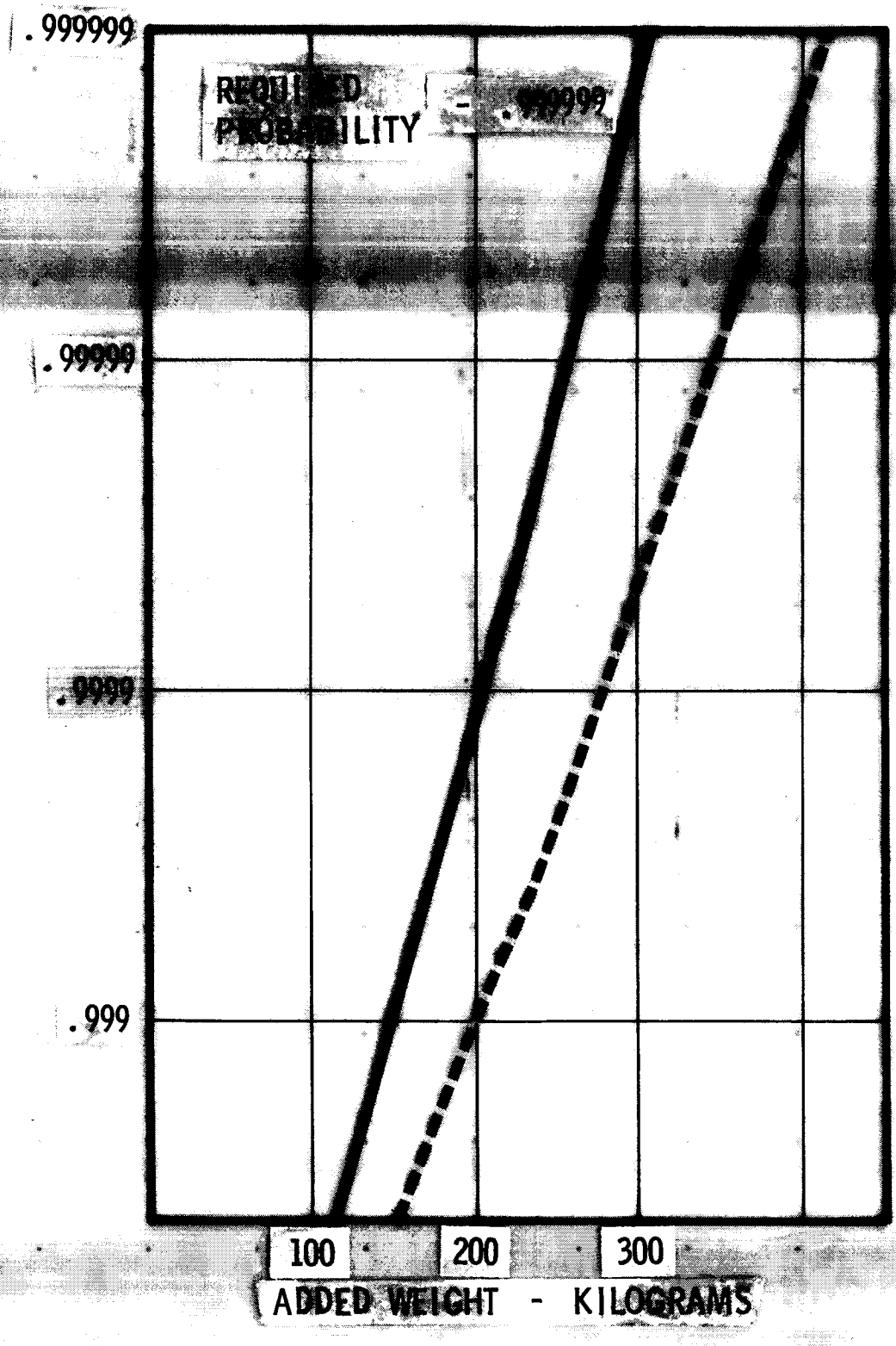



Figure 1-4 MAINTENCE CONCEPT COMPARISON ELECTRICAL POWER SUBSYSTEM

## I.5 EXPERIMENT SUBSYSTEM (FIGURE I-5)

In the first analysis of the experiment subsystem, complete probes were identified as spare or backup units for the Degree "0" maintenance concept. This approach resulted in the curve identified as "B." In a practical application of this concept, all probes probably would be launched whether they checked out or not. The end result is that over 28,000 kilograms of probes and experiment packages were added to achieve 0.99 probability of mission success. The total effect of sparing complete probes on mission weight could be reduced somewhat by eliminating all probe checkout which requires equipment in addition to that required for monitoring and control of the probes. The added weight resulting from this approach was so large that a second analysis considering a different approach to designing for Degree "0" maintenance was run. In the second analysis the probes were improved to the required level of reliability by adding fixed increments of parallel redundancy within the probes. The basic increment was assumed to be the weight of the repair kit identified for the Degree "2" concept. This weight was spread statistically over all the mechanisms within the probe every time a level of parallel redundancy was added. The result of the second analysis is indicated by the curve labeled "A." The curve of the Degree "2" concept subsystem and curve "A" are indistinguishable on the gross scale. Greater detail is shown on the insert in the lower right corner of the figure. The small penalty of the Degree "0" maintenance subsystem (curve "A") over the Degree "2" maintenance subsystem indicates that additional configuration and trade studies could be worked on the probes to be carried. It is felt that the on-board experiment packages, used during midcourse and planetary passage, should be repairable by Degree "3" maintenance because of the flexibility that probably will be required to adapt the experiments to unanticipated conditions and observational requirements. If the on-board experiment packages are designed for flexibility, it is felt that it is a small step to providing repair capability for the experiments.

Because of a high degree of uncertainty, experiments were not costed and a relative cost difference between maintenance concepts was not determined. The average unscheduled repair time is expected to be about 560 minutes, and will occur about every 680 days. The high average repair time is due primarily to the character of the repair actions to be accomplished on the probes. Repair of the probes was considered to be difficult and time-consuming due to the limited work space and the inaccessibility of the internal mechanisms.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REQUIRED PROBABILITY = .999999
.99999
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ADDED WEIGHT - KILOGRAMS

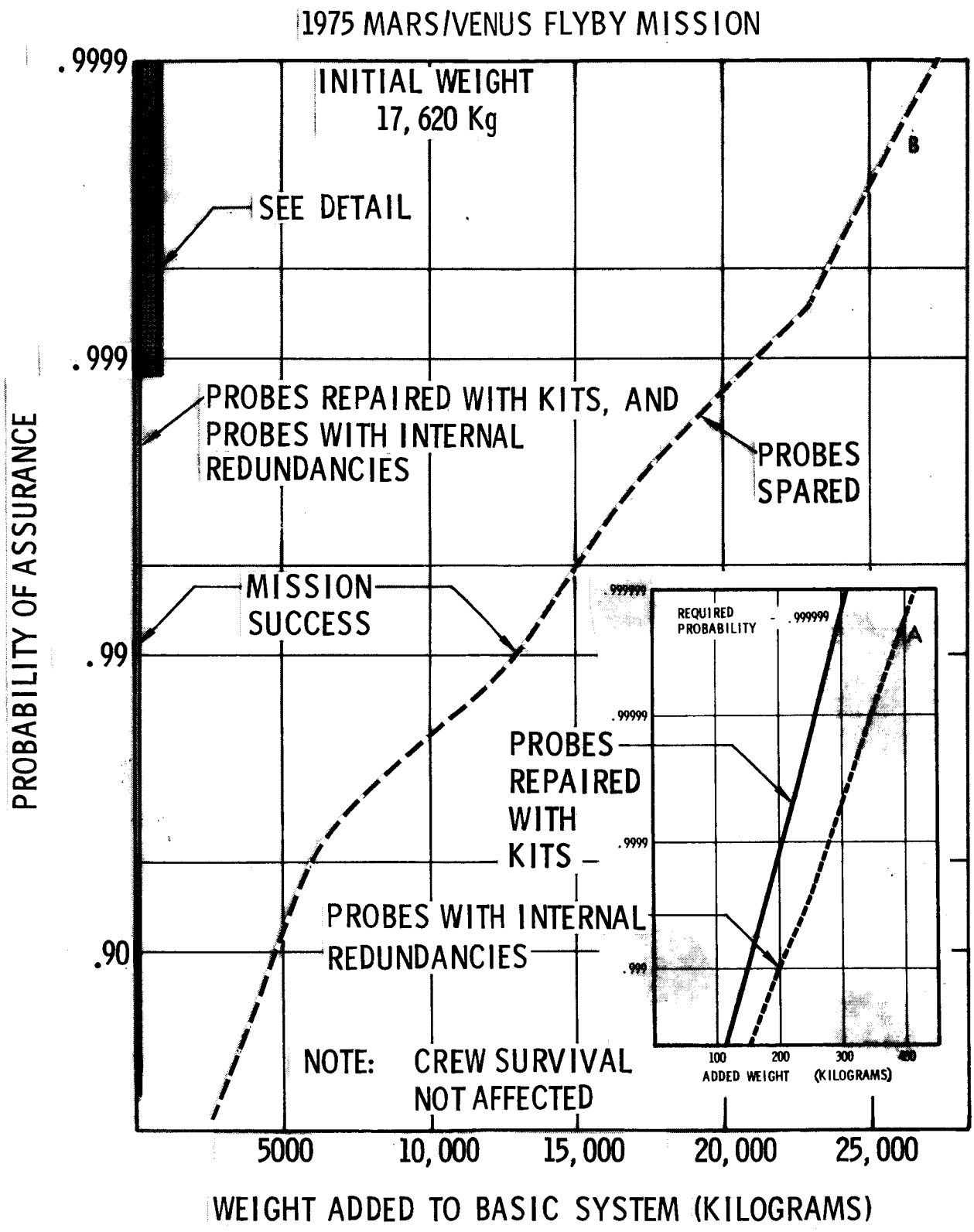


Figure I-5 MAINTENANCE CONCEPT COMPARISON — Experiment System

## I.6 EXTRAVEHICULAR ACTIVITY SUBSYSTEM (FIGURE I-6)

The extravehicular activity subsystem includes such items as pressure suits, power locomotion devices, airlocks, etc. In the analysis of the maintainable subsystem these items were repaired by kits. In the "nonmaintainable" analysis, these items were added in redundancy or as gross spares. The pressure suits, maneuvering units, and similar items were spared as complete units because parallel or standby redundancy could not be rationalized for them. Items such as the airlock were allowed to be added in fixed redundancy, even though this might not be a solution to an airlock failure.

It can be seen from the figure that repair of the EVA subsystem achieves a significant advantage over the nonrepairable subsystem. From a purely safety standpoint, an airlock repair capability, at least to the extent of replacing seals and closing mechanisms, is highly desirable. For the same reason, a backup spare suit would seem desirable; however, it was determined in the simulation analyses that an event that required all the crew to be in suits when one suit happened to be under repair was highly unlikely. In a simulation of 200 missions this event did not occur at all.

In general, Degree "3" maintenance is recommended as the concept for the EVA subsystem. It is necessary that the airlock can be repaired by a pressure-suited man even though the repair action may take place within the pressurized compartment. To ensure crew safety, it is expected that tasks related to the pressure integrity of the hull will require all suits on (possibly with face-plates up) even though loss of pressure is not expected.

The Degree "2" maintenance concept will result in a mean unscheduled repair time of 190 minutes. The repair actions will occur about every 1770 days. The relative cost difference is 0.009 in favor of the Degree "2" maintenance concept.

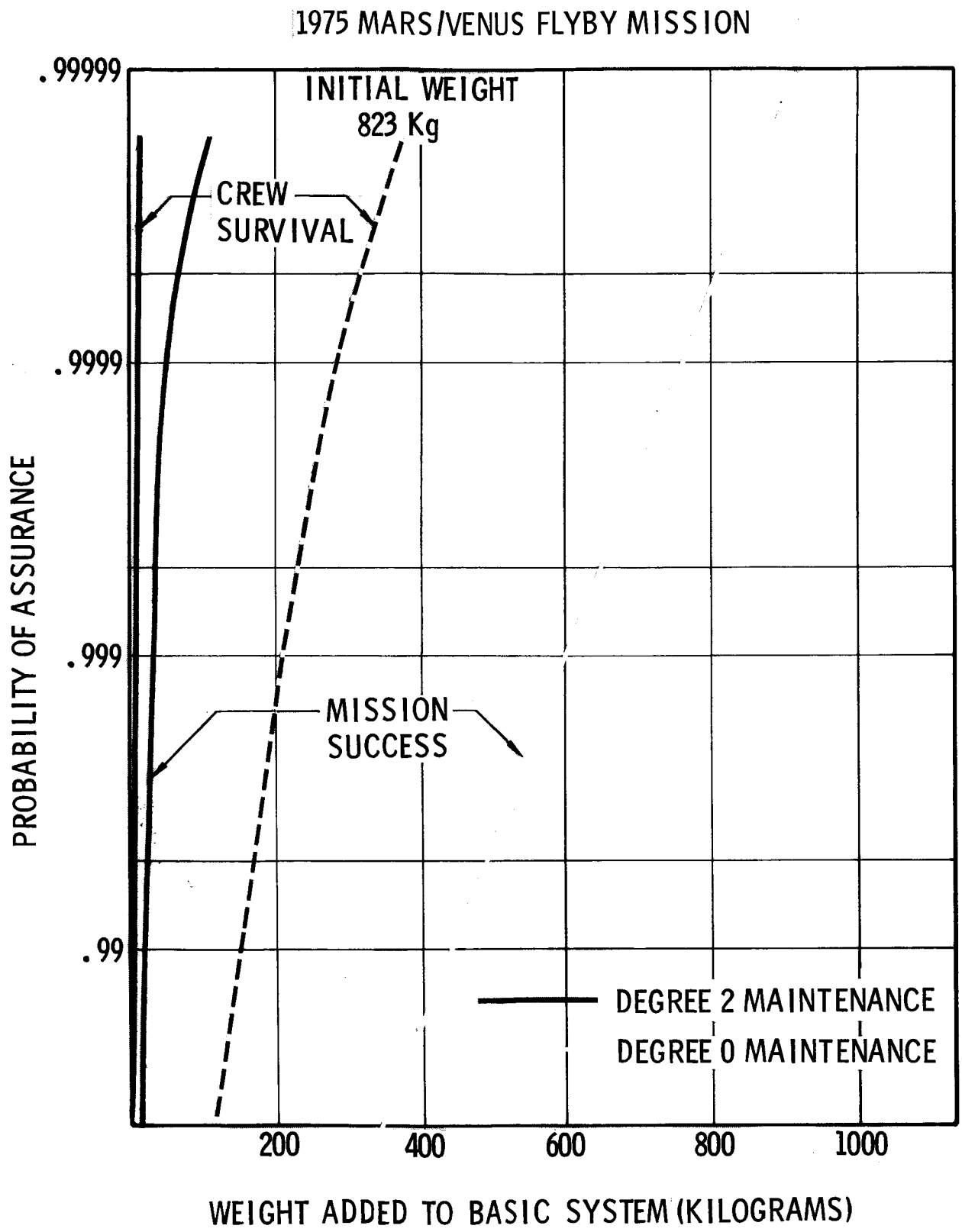


Figure I-6 MAINTENANCE CONCEPT COMPARISON — Extravehicular Activity Subsystem

## I.7 INFLIGHT TEST SUBSYSTEM (FIGURE I-7)

First inspection of the figure seems to indicate that designing the inflight test subsystem to eliminate maintenance might be desirable in view of the relatively low weight penalty. However, there are some hidden effects of designing parallel redundant (the dominant mode of addition) test indicators that are undesirable. Parallel redundant indicators will require additional panel area and weight increase. A first estimate indicates that panel area will increase between two and three times the basic panel area. Other hidden effects are the increased power drain and the increased probability of operator confusion and error. The maintenance time recorded for the subsystem appears to be relatively high in comparison to the size of the subsystem; however, the estimated task times for this subsystem are all quite pessimistic.

The fault indicator panel, which was planned as a matrix of lights, could be a problem. Recent developments in solid state lamps and mechanical flag indicators may be incorporated in place of indicator lamps and achieve a significant decrease in the number of indicator failures expected.

The relative cost difference between the competitive concepts is 0.001 in favor of the Degree "2" maintenance concept. The average unscheduled repair time was found to be about 80 minutes with repair actions occurring every 39 days on the average.

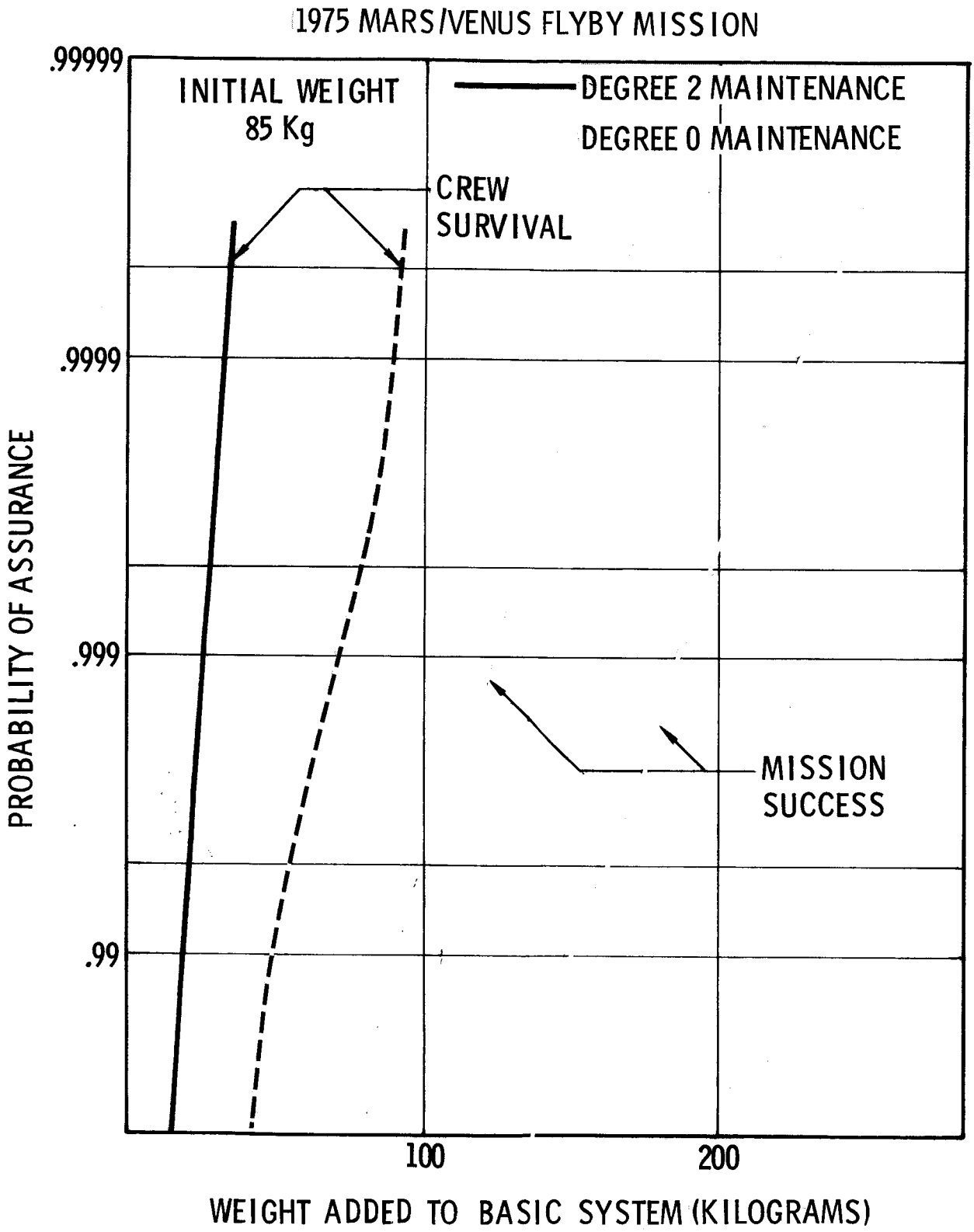


Figure I-7 MAINTENANCE CONCEPT COMPARISON — Inflight Test Subsystem

## I.8 LIFE SUPPORT SYSTEM (FIGURE I-8)

It should be noted that the no-maintenance approach applies to unscheduled maintenance only. Scheduled maintenance activities such as filter, wick, and catalyst changes have not been automated. Automation of these activities is possible only if the operating life of these elements can be significantly increased.

It is apparent from the figure that Degree "2" maintenance is the proper selection over the Degree "0" concept. In order to achieve this goal, careful placement of the life support subsystem within the mission module is necessary, as well as careful location of subsystem components in relation to each other. The only general recommendations with regard to component location are that scheduled maintenance items be immediately accessible, and those requiring servicing weekly or more frequently should be accessible without removal of any access panel. High failure rate items should be given next priority in location. With regard to subsystem placement, it is recommended that the subsystem be located so that component accessibility can easily be achieved. The placement of this subsystem is of concern because it contributes a major portion to the total maintenance load for the entire spacecraft. One placement arrangement that seems to be advantageous is locating the subsystem centrally in a disk or washer-shaped space between living and working spaces of the mission module. This configuration would provide accessibility to equipment from both sides, and when covered by relatively light sealed cover panels, would provide a capability to isolate the crew compartments and to work on the subsystem from a pressurized compartment in the event the other were depressurized.

The relative cost difference between the maintenance concepts is 0.026 in favor of the Degree "2" concept. The expected unscheduled repair time was found to be 143 minutes per failure with the failures expected to occur about every 37 days.

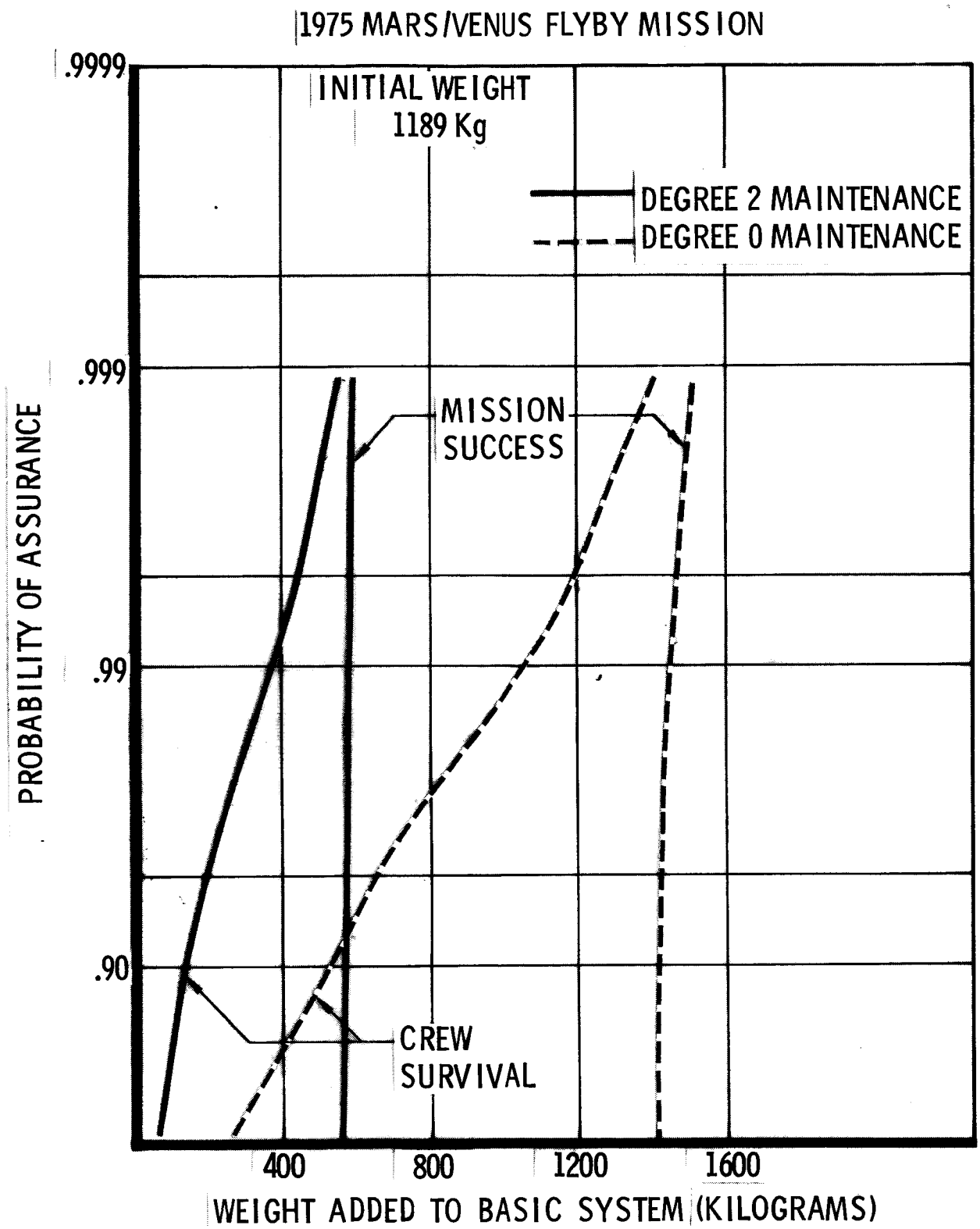


Figure 1-8 MAINTENCE CONCEPT COMPARISON
Life Support Subsystem

## I.9 NAVIGATION AND GUIDANCE SUBSYSTEM (FIGURE I-9)

The small difference in the weights added for the two different maintenance concepts indicates that redundancy might be preferred over a Degree "2" maintenance for this subsystem. This seems to be a logical choice with some minor exceptions. Redundancy is desirable for optical elements and the inertial platform because of possible alignment problems caused by replacement. The skill level required to make replacement of these items is also felt to be high in relation to that required by other subsystems. The electronics packages related to the optical equipment and to the inertial platform were added in standby redundancy for the Degree "0" concept. It seems quite reasonable to spare these items because fault indication could be automatic and to indicate a replaceable circuit board that would require a minimum amount of tools and maintenance time.

A relative cost difference of 0.006 was found in favor of the Degree "2" concept. The average unscheduled repair time was determined to be 364 minutes per failure. The interval between failures is expected to be about 66 days which makes this subsystem second only to the data management subsystem in its impact on the unscheduled maintenance workload.

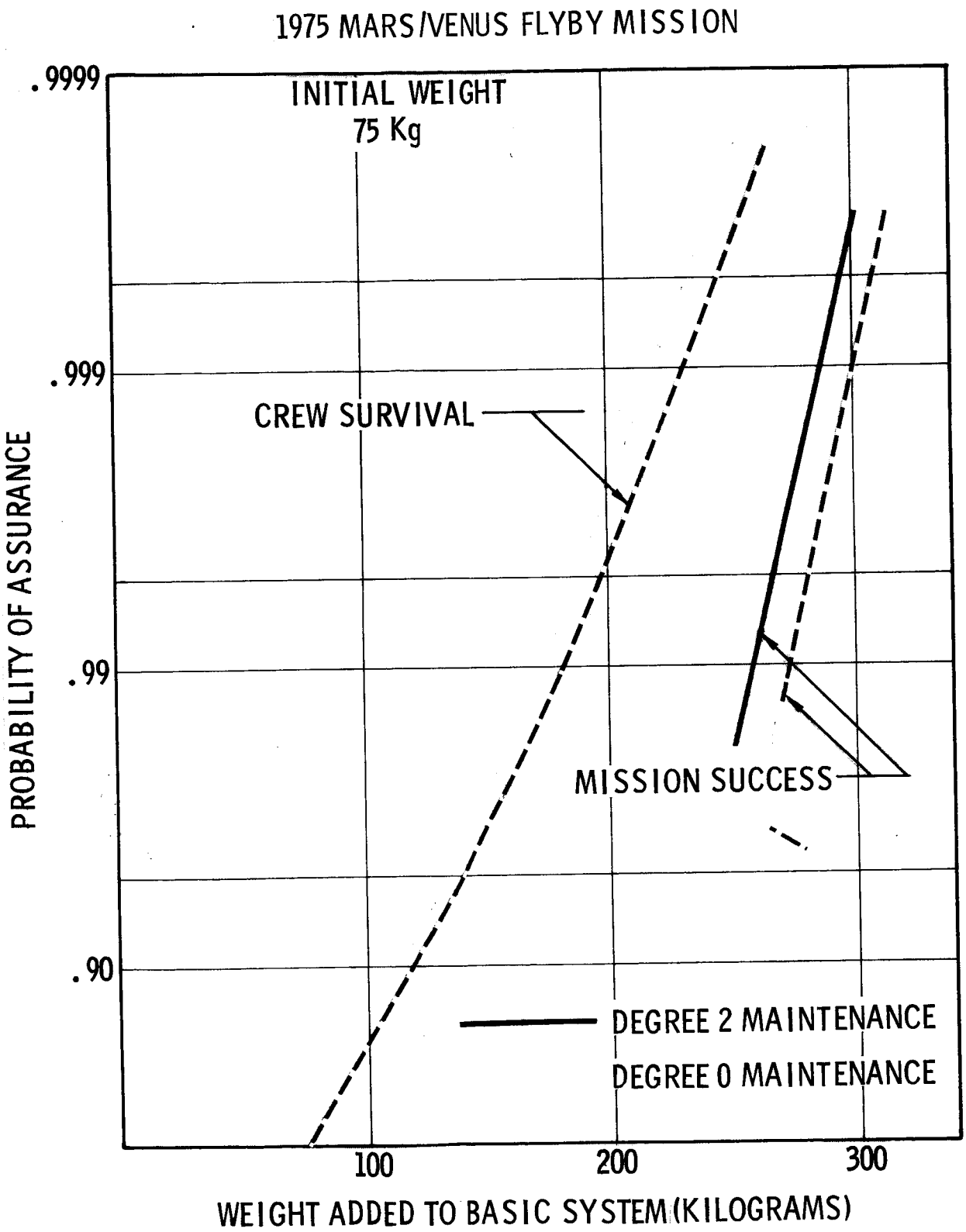


Figure I-9 MAINTENANCE CONCEPT COMPARISON — Navigation & Guidance Subsystem

## I.10 PROPULSION SUBSYSTEM (FIGURE I-10)

It is apparent from the curves that a maintenance capability is desirable for the propulsion subsystem. This subsystem includes the reaction control equipment necessary to control the spacecraft's attitude, and the midcourse correction propulsion equipment. Maintenance on the reaction control modules should be relatively easy compared to that required on the midcourse hardware. Degree "3" repair of some of the reaction control modules might be considered. In this event, the failed module would be removed from the reaction control package and brought into the spacecraft for replacement of the failed item within the module.

The midcourse correction hardware will be more of a maintenance problem because of the size and inaccessibility of the equipment. It is felt that these problems can be overcome if Degree "2" maintenance is planned for during the design of the equipment. The important thing is that the necessary maintenance actions are anticipated before the hardware is configured.

The backpacks required with the pressure suits for EVA are estimated to consume 0.68 kilogram of water per hour of use. This leads to a maximum expected total accountable to the propulsion subsystem of 441 kilograms. This factor significantly decreases the advantage of maintenance. Design of the spacecraft and the suits to permit external connection of the suits to the interior life support system could regain a significant part of the advantage lost. This capability would also have an impact on the maintenance of other subsystems, particularly the electrical power and communications subsystems.

The expected unscheduled repair time determined for the 1975 Mars/Venus flyby mission was about 250 minutes per failure, which was expected to occur about once every 58 days. All repair actions required at least two men because the activity was all extravehicular. The relative cost difference was found to be 0.020 in favor of the Degree "2" maintenance concept.

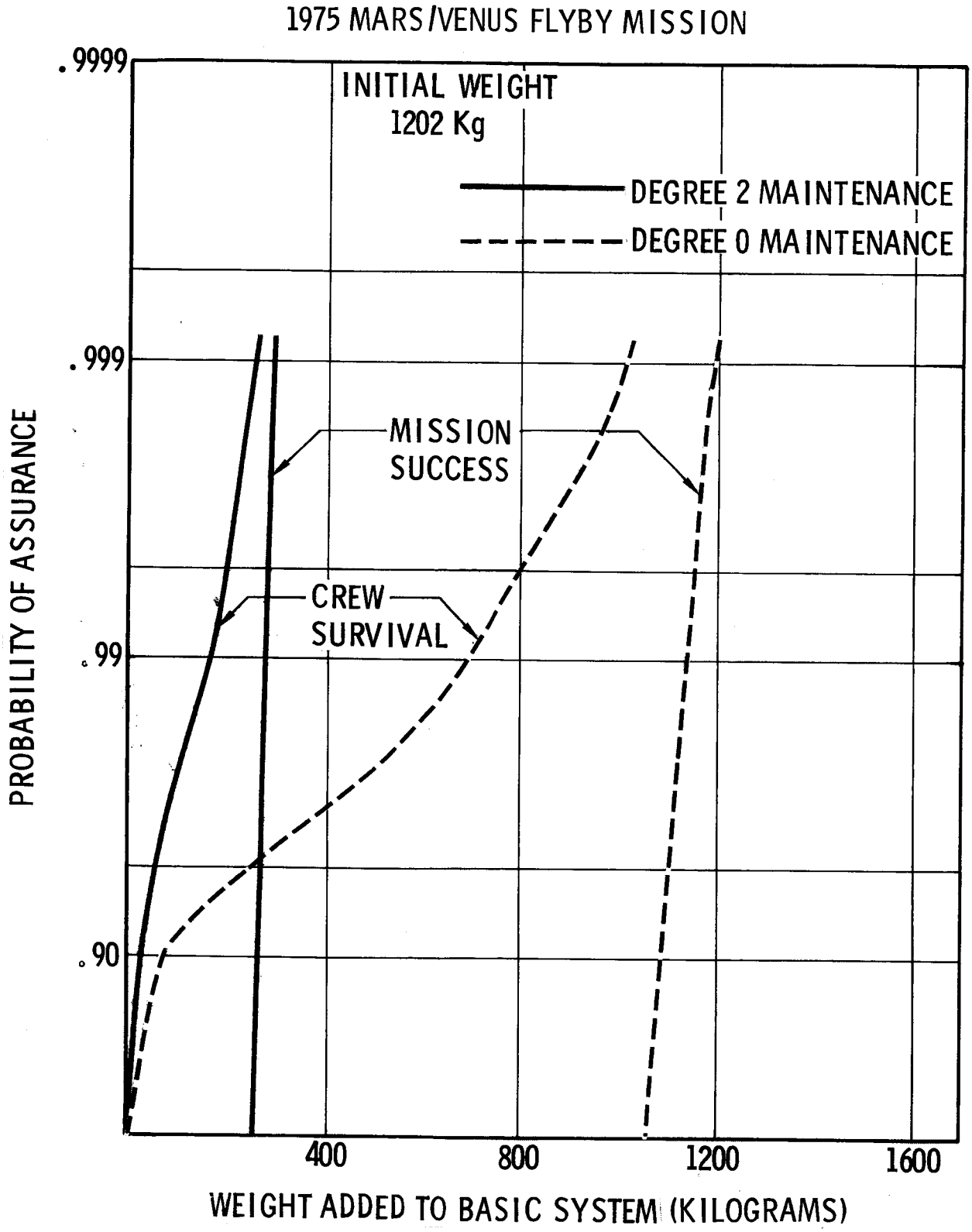


Figure I-10 MAINTENANCE CONCEPT COMPARISON — Propulsion Subsystem

## I.11 EARTH REENTRY SUBSYSTEM (FIGURE I-11)

The Earth reentry subsystem (the six-man uprated Apollo class vehicle) is one of those subsystems required almost entirely for crew survival. For this reason, no mission success curves are indicated. For the analysis of the Degree "2" concept, each of the Earth reentry vehicle (ERV) subsystems was assigned a repair kit of what was felt to be appropriate size. These kits served to repair the ERV subsystems whenever a failure was found during periodic checkouts of the ERV.

For the Degree "0" concept analysis, each of the gross subsystems was allowed to be added in redundancy. The analysis selected standby redundancy universally for all ERV subsystems having additions. It is recognized that this will result in a heavier added weight than could be obtained if the ERV subsystems were analyzed to a greater level of detail. No attempt to go into greater depth on the ERV was made because this was beyond the scope of this study. Looking at the ERV at the level of depth shown, it is still a good estimate that Degree "2" maintenance should be performed on it.

Relative costs were not calculated for the Earth reentry vehicles. The expected unscheduled repair time was found to be about 440 minutes per failure. Failures are expected to occur about every 1830 days.

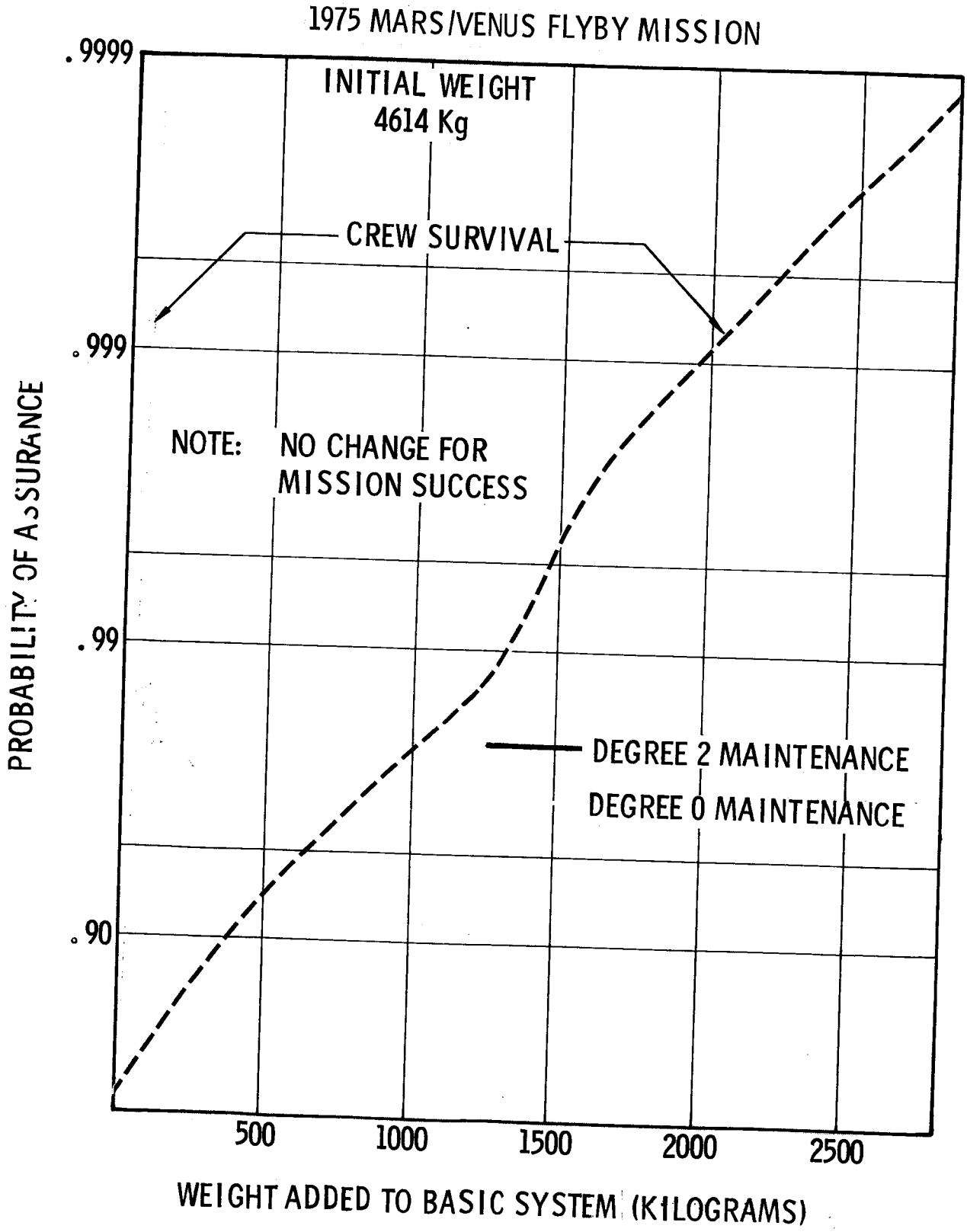


Figure I-11 MAINTENANCE CONCEPT COMPARISON — Reentry System

## I.12 STABILITY AND CONTROL SUBSYSTEM (FIGURE I-12)

The stability and control subsystem is the electronic part of the total loop which controls the spacecraft attitude. This equipment is located in the pressurized spacecraft and can be modularized easily into replaceable packages or circuit boards. As the subsystem appears to be remarkably devoid of problems and trouble spots that might impair the performance of maintenance, Degree "2" maintenance is recommended for this subsystem.

The relative cost difference between the competitive maintenance concepts was found to be 0.004. The mean unscheduled repair time was determined to be 172 minutes per failure, with failures occurring about every 78 days.

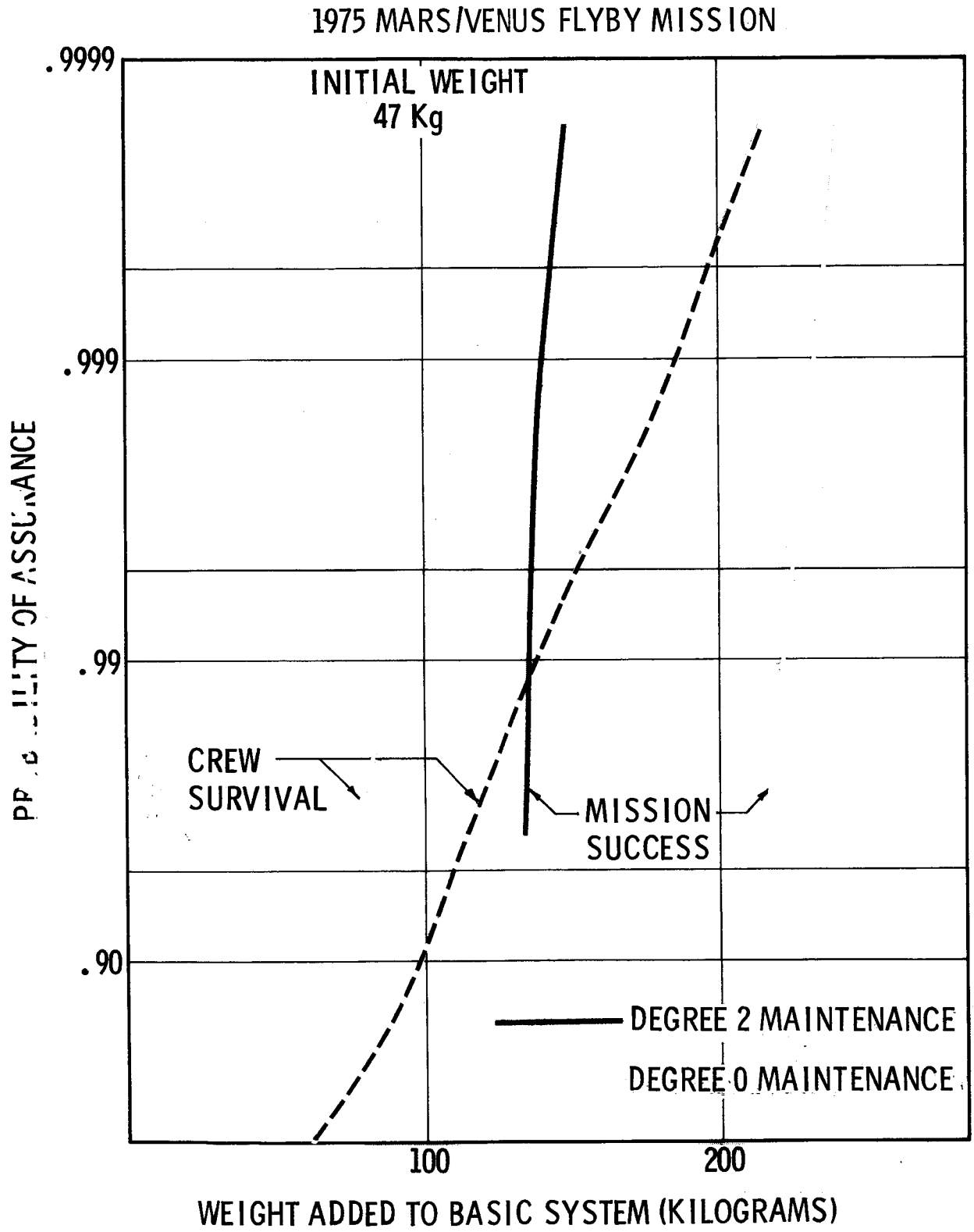


Figure I-12 MAINTENANCE CONCEPT COMPARISON — Stability and Control Subsystem

## I.13 STRUCTURE SUBSYSTEM (FIGURE I-13)

For a subsystem with an initial weight of 16,628 kg, relatively little weight was added to improve the mission probabilities. This is because of the low structural failure rate assigned and because repairs were made by kit in most cases. In applying the Degree "0" concept, it was considered illogical to add parallel, standby, or even spare structural elements (these are the mission module hull, the interior structure, the probe compartment, etc.). For this reason, redundancies were limited to a few selected items in the structure subsystem that were felt to be appropriate. This is apparent in the small difference in weight between the curves. In general, Degree "3" maintenance is recommended for the structure subsystem. When repair is considered, the expected unscheduled repair time will be about 430 minutes, and repairs are expected to occur about every 1770 days. The repair concept, Degree "3" maintenance, will cost relatively less than the Degree "0" concept by 0.012.

Design and configuration of the structure are critical to maintenance concepts considered for the various spacecraft subsystems. In particular, the configuration of the spacecraft internal compartments is critical to planned maintenance on the subsystems located in the pressurized compartment. The greatest interface impact is between the life support subsystem (LSS) and structure, because of the large amount of space the LSS occupies and its inherent tendency to inaccessibility. Location of the LSS against the pressure hull about the center section of the mission module or at either end of the mission module has the advantage of being volumetrically efficient and adds a measure of radiation shielding to the interior of the mission module. Unfortunately, this configuration tends to be highly inaccessible for both scheduled and unscheduled maintenance and makes the hull difficult to patch from the interior due to the layer of equipment that must be penetrated to reach the hull. In general, it can be said that the structure subsystem interfaces with the maintenance concepts selected for the remaining subsystems. The degree of the interface and the impact of the interface on weight and maintenance time are determined by the subsystem components, the subsystem maintenance concept, and the configuration placement of the subsystem in relation to the spacecraft structure. Making general recommendations in this area is felt to be highly risky at the present time. Detailed configuration trade studies for spacecraft internal arrangement should be made considering weight, crew comfort, operability, radiation shielding effects of equipment, radiation shelter requirements, and equipment accessibility for maintenance.

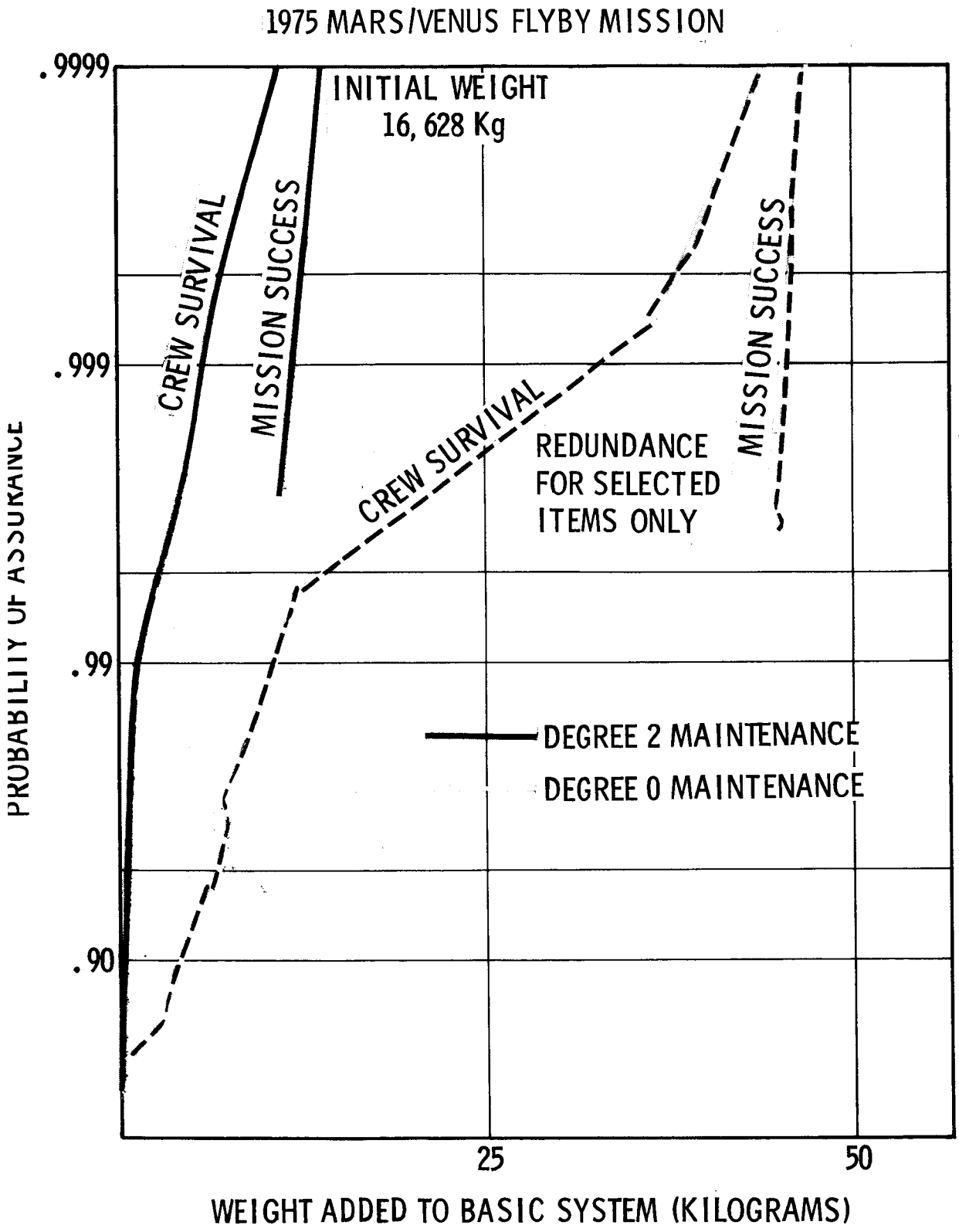


Figure I-13 MAINTENANCE CONCEPT COMPARISON — Structure Subsystem