REPORT ON THE DEVELOPMENT OF THE MANNED ORBITAL RESEARCH LABORATORY (MORL) SYSTEM UTILIZATION POTENTIAL

TASK AREA III
MORL CONCEPT RESPONSIVENESS ANALYSIS

BOOK 1

SM-48813
NOVEMBER 1965

MISSILE & SPACE SYSTEMS DIVISION
DOUGLAS AIRCRAFT COMPANY, INC.
SANTA MONICA/CALIFORNIA

DOUGLAS

REPORT ON THE DEVELOPMENT OF
THE MANNED ORBITAL RESEARCH LABORATORY (MORL)
SYSTEM UTILIZATION POTENTIAL

Task Area III
MORL Concept Responsiveness Analysis

BOOK 1

SM-48813
NOVEMBER 1965

PREPARED BY N. KALLAY
BRANCH CHIEF
SYSTEMS ENGINEERING

APPROVED BY C E Starns
C. E. STARNS
PROGRAM MANAGER

SUBMITTED BY
DOUGLAS AIRCRAFT COMPANY, INC.

PRESENTED TO
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LANGLEY RESEARCH CENTER
CONTRACT NO. NAS1-3612

APPROVED BY RJ Gunkel
R. J. GUNKEL
DIRECTOR, ADVANCED MANNED SPACECRAFT SYSTEMS

DOUGLAS MISSILE & SPACE SYSTEMS DIVISION

The Manned Orbital Research Laboratory (MORL) is a versatile facility for experimental research which provides for:

- Simultaneous development of space flight technology and man's capability to function effectively under the combined stresses of the space environment for long periods of time.

- Intelligent selectivity in the mode of acquisition, collation, and transmission of data for subsequent detailed scientific analyses.

- Continual celestial and terrestrial observations.

Future application potential includes use of the MORL as a basic, independent module, which, in combination with the Saturn Launch Vehicles currently planned for the NASA inventory, is responsive to a broad range of advanced mission requirements.

The laboratory module includes two independently pressurized compartments connected by an airlock. The larger compartment comprises the following functional spaces:

- A Control Deck from which laboratory operations and a major portion of the experiment program will be conducted.
- An Internal Centrifuge in which members of the flight crew will perform re-entry simulation, undergo physical condition testing, and which may be useful for therapy, if required.
- The Flight Crew Quarters, which include sleeping, eating, recreation, hygiene, and liquids laboratory facilities.

The smaller compartment is a Hangar/Test Area which is used for logistics spacecraft maintenance, cargo transfer, experimentation, satellite checkout, and flight crew habitation in a deferred-emergency mode of operation.

The logistics vehicle is composed of the following elements:

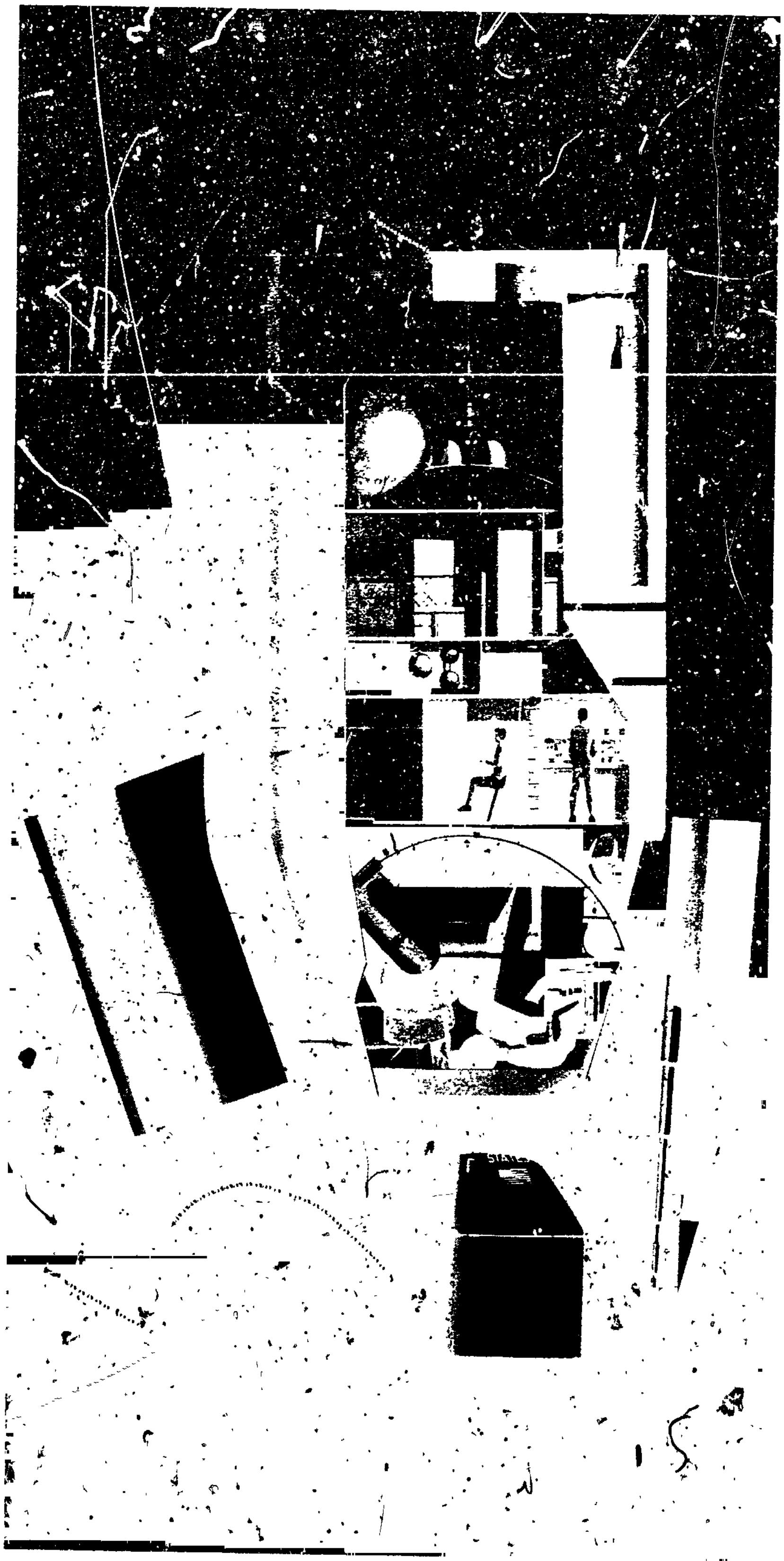
- A Logistics Spacecraft which generally corresponds to the geometric envelope of the Apollo Command and Service Modules and which includes an Apollo Spacecraft with launch escape system and a service pack for rendezvous and re-entry maneuver propulsion; and a Multi-Mission Module for either cargo, experiments, laboratory facility modifications, or a spacecraft excursion propulsion system.
- A Saturn IB Launch Vehicle.

Integration of this Logistics System with MORL ensures the flexibility and growth potential required for continued utility of the laboratory during a dynamic experiment program.

In addition to the requirements imposed by the experiment program, system design parameters must reflect operational requirements for each phase of the mission to ensure:

- Functional adequacy of the laboratory.
- Maximum utilization of available facilities.
- Identification of important parameters for consideration in future planning of operations support.

For this reason, a concept of operations was developed simultaneously with development of the MORL system.




STATES

PREFACE

This report is submitted by the Douglas Aircraft Company, Inc., to the National Aeronautics and Space Administration's Langley Research Center. It has been prepared under Contract No. NAS1-3612 and describes the analytical and experimental results of a preliminary assessment of the MORL's utilization potential.

Documentation of study results are contained in two types of reports: a final report consisting of a Technical Summary and a 20-page Summary Report, and five Task Area reports, each relating to one of the five major task assignments. The final report will be completed at the end of the study, while the Task Area reports are generated incrementally after each major task assignment is completed.

The five Task Area reports consist of the following: Task Area I, Analysis of Space Related Objectives; Task Area II, Integrated Mission Development Plan; Task Area III, MORL Concept Responsiveness Analysis; Task Area IV, MORL System Improvement Study; and Task Area V, Program Planning and Economic Analysis.

This document contains 1 of 2 parts of the Task Area III report, MORL Concept Responsiveness Analysis. This analysis compares the capability of the baseline MORL concept to the mission requirements as defined in the Task Area II report. Potential solutions for marginal capabilities are also identified and recommendations for further analysis in Task Area IV are made.

The ns and identification of the two parts of this report are as follows: Book 1, Douglas Report SM-48813, presents the results of this assessment; it is supplemented by Book 2, Douglas Report 48814, in which the assessment is based on a detailed examination of a 48-hour segment of on-board operations which are subjected to the same mission requirements.

Requests for further information concerning this report will be welcomed by R. J. Gunkel, Director, Advance Manned Spacecraft Systems, Advance Systems and Technology, Missile & Space Systems Division, Douglas Aircraft Company, Inc.

PRECEDING PAGE BLANK NOT FILMED.

CONTENTS

PRECEDING PAGE BLANK NOT FILMED.

FIGURES

TABLES

Section 1
INTRODUCTION AND SUMMARY

The purpose of the Task Area III Study (MORL Responsiveness Analysis) was to determine the ability of the MORL to fulfill the requirements of the Mission Development Plan. The plan was formulated from the analyses of Task Areas I and II.

As discussed in Book 1 of Task Area II (SM-48810), the Mission Development Plan provided initially for a 3-to 5-year R&D-oriented program of basic experiments that could be completed in a low-altitude, low-inclination orbit. The R&D program was designed to develop the information necessary to implement subsequent, highly objective-oriented, experimental programs. It was anticipated that, with the conclusion of the initial R&D mission, these highly objective-oriented programs would be selected and assigned to MORL. Specifically, the following three basic requirements were imposed on MORL:

1. MORL must support a broad scientific and technological research program designed to develop the basic data, information, and techniques necessary to implement subsequent, highly objective-oriented, experimental programs. The broad-based research program consists of those experiments listed in the Experiment Plan of Task Area II.
2. MORL must also support a highly objective experimental program designed to fully implement one or more clearly defined scientific, technological, or industrial applications of space stations. Such a program was selected from the Applications Plan of Task Area II.
3. MORL must operate in polar and synchronous orbits, either singly or simultaneously with other modules, in a resuppliable mode. These orbits were examined because they may be required for the highly objective-oriented programs.

Thus, to be completely responsive to projected needs, the MORL must be not only capable of meeting the requirements of an R&D program with a broad base, but must also be capable of supporting the requirements of application-oriented programs.

In this study, the requirements imposed by the broad-based experimental program, the objective-oriented program, and the two alternate orbits were first determined. The capabilities of the baseline MORL were then examined to determine the degree to which MORL could satisfy these requirements.

1.1 MORL ACCOMODATION OF THE EXPERIMENT PLAN

The MORL accommodation of the requirements imposed by the broad-based Experiment Plan was studied in a two-fold manner. The first approach investigated the adequacy of the resources of the MORL in the light of the quantity necessary to accommodate the experimental program. The second approach studied the performance of the various MORL subsystems as compared to that necessary to perform the individual experiments.

1.1.1 Adequacy of MORL Resources

This approach established the basic requirements for each experiment, such as weight, power, duration, crew skill, and so forth, and used these as the input into a digital computer program. The program titled the Systems Planning and Effectiveness Evaluation Device (SPEED) simulated and scheduled all events on board an orbiting MORL. In essence a time lined Experiment Plan was constructed by comparing the resource and scheduling requirements of the individual experiments to the MORL resource availability. The following conclusions were reached:

1. The size of the six-man MORL is adequate to complete the R&D oriented MORL Experiment Plan. The study showed that in carrying out the Experiment Plan, the efficiency of the MORL facility was high. Utilization of the major experiment support parameters, such as crew time and shipping weight, was near 100%. The factors which limit the rapidity with which the experimental program could be accomplished appeared to be the availability of crewmen and their respective skills. Analysis has indicated that changes in the crew skill mix have a significant effect on the time required to complete a given set of experiments. Worthwhile reductions in program duration could be made by not only adjusting the crew skill mix, but also by increasing the crew size. An increased number of crewmen can provide a better system load factor balance, allow more flexibility in the skill mix assignments, provide more skills, and allow a larger number of man-hours to be devoted to experiments.

It is therefore recommended that the effectiveness of a nine-man crew in accomplishing the Experiment Plan on MORL be determined.

2. The experiments in the Experiment Plan were scheduled and completed in accordance with the requirements of the plan. Delays caused by the unavailability of resources were minimal. The effect of subsystem failures and subsequent repair operations were simulated and found to have an insignificant effect on the program operation.

In order to complete the first part of the responsiveness analysis, a portion of the Experiment Plan was also examined in depth. This was accomplished to provide insight into the detailed problems that can be encountered in carrying out an in-space experimental program. The analysis considered the location of experimental equipment, crew timeline histories, detailed failure and repair functions, and detailed laboratory operations. The conclusions and recommendations resulting from this analysis are documented in Book 2 (SM-48814) of this task area report.

1. 1. 2 Subsystem Performance

The second approach, used to establish the extent to which MORL meets the requirements of the program, consisted of determining the demands made by the experiments on the performance of the MORL subsystems, and then comparing these demands with the capabilities of the subsystems. The results are outlined in the paragraphs below.

1. 1. 2. 1 Stabilization and Control

Of the 102 representative experiments found to impose requirements on the Stability and Control System (SCS), 13% can be accommodated without changes to the baseline design. (The MORL baseline design referred to in this book is the design documented at the end of the Phase IIa study Douglas Reports SM 46071 through SM 46100). The primary limitations are due to the fact that the experimental requirements exceed the baseline stabilization or slew rate capability. However, if the baseline precision attitude reference is used in conjunction with a rigid sensor/experiment mount and those experiments which exceed the rate control capability of the baseline system were gimbal mounted, the accommodation of the experiments examined is increased to 86%.

Further improvements can be made by tightening the attitude control capability of the SCS. The number of experiments which can be accommodated by the SCS is, therefore, a function of the capabilities of the baseline system. It is recommended that the confidence in actually attaining these capabilities be improved by further study in the following areas:

1. The ability of the SCS to maintain the 0.5° attitude hold accuracy must be substantiated.
2. The estimated disturbance rates induced by crew motion must be verified by further study, simulation, and inflight testing.
3. The capability of the precision attitude reference system in combination with the SCS must be determined.

1.1.2.2 Environmental Control and Life Support

Only minor Environmental Control and Life Support System (EC/LS) modifications will be required to accommodate the Experiment Plan. Since a major portion of the experiments will be performed in the MORL hangar section, a separate cooling and ventilation system should be installed in that area to provide proper temperature and comfort control. The changes that would be required to accommodate a larger crew should also be determined. Preliminary analyses indicate that these changes could be easily adapted to the baseline system. The EC/LS system weight increase required to support a nine-man laboratory was found to be approximately 550 lb.

1.1.2.3 Structures

The Structures and Configuration System was examined to establish the systems ability to support the experimental activity on board the laboratory. A console and operator panel should be added in the hangar section to provide experiment control flexibility. In addition a rigid mount should be installed to provide a base for experiment sensors that require great accuracy and stability. The baseline scientific console should also be modified to provide the capability of multiple experiment control and monitoring.

1.1.2.4 Communications

The Communications System was found to have insufficient data management capacity. The following four areas should be investigated to determine their effect in increasing this capacity:

1. A single programmable data acquisition and distribution function which is central to all other subfunctions.
2. An all-digital data distribution bus with local analog-to-digital (A-D) conversion.
3. A single data channel telemetry function with interrupt capability.
4. The capability to reduce operational and experimental data on board.

Generally inflexible experimental requirements were used in the studies of subsystem responsiveness. In some cases, severe experimental requirements were imposed because of inadequate definition of the purpose of the experiment, and/or because of the uncertainty of their effect on the laboratory capabilities. These severe requirements compounded problems arising out of a conflicting need for the laboratory resources.

To remedy this situation, the experiment and the laboratory in which it will be performed must be considered as a design unit. The laboratory/experiment interface must be iteratively improved by successive and coordinated changes in the experiments as well as in the laboratory. The application of this procedure is partly responsible for the efficient utilization of the MORL (nearly 100%). However, further refinements in MORL subsystem designs appear to be highly dependent on more detailed experiment definitions and redefinitions prepared in close coordination with the subsystem designers.

1.2 MORL ACCOMMODATION OF THE OBJECTIVE ORIENTED PROGRAM

An objective oriented program selected for analysis from the Applications Plan, was one necessary to the evolution of all techniques and instruments used in a program of routine assistance to Fisheries Production. This program was selected to illustrate the effectiveness of the MORL, should such a program be selected for implementation. The study found that MORL resources were adequate to meet the demands of the Fisheries Production program. In addition, the crew skill mix was found to be somewhat critical, since the time required to complete the Fisheries Production program was quite sensitive to this parameter. For example, when the skill of one member of the crew was changed from that of meteorologist to oceanographer, the required program duration was reduced by approximately 12%.

1.3 ALTERNATE MORL MISSIONS

It was found that the requirements of the experiments in the Experiment Plan could be satisfied in a low-altitude and low-inclination (30 to 60° inclination) orbit. The orbit parameters of the baseline MORL design are 200-nmi altitude and 50° inclination. However, since a highly objective-oriented program may require operation in a polar as well as in a synchronous orbit, it was decided to determine the effect of conditions in these two orbits on the baseline MORL. It was found that except for additional radiation protection, changes required to the baseline MORL laboratory design to accommodate these missions would be minor. However, a Saturn V launch vehicle will be required for the polar and synchronous missions.

The polar mission can be accommodated by making the following changes to the baseline system:

1. An addition of 1,820 lb of shielding material must be made to the basic structure to attenuate the increased radiation to an acceptable dose level.
2. One tracking site (probably at Guaymas) must be added to the two baseline sites at Cape Kennedy and Corpus Christi in order to provide the navigation accuracy required.
3. Launch from Cape Kennedy, with the attendant range safety restrictions, reduces the orbit payload to such a value that a Saturn V launch vehicle is required for the polar mission.

The MORL should not be committed to the synchronous mission until further studies are completed. At present, it appears that the current MORL cannot accommodate the synchronous mission because of the large amount of radiation shielding required. However, the many uncertainties in this analysis deem that certain studies (discussed in subsequent paragraphs) be completed prior to a firm decision. When the nominal intensity of the electron environment at this altitude (as defined by Reference 1) is used, the required shield material that must be added to MORL in order to attenuate the dose received to an acceptable level, is approximately 20 tons. However, because of the above mentioned uncertainties in the magnitude of the radiation environment at this altitude, the corresponding variation in required shield weight is from 4,400 to 110,000 lb. The maximum weight allowance that could be allotted to radiation shielding on the laboratory launch is approximately 30,000 lb (when zero discretionary payload is assumed). Even if the material could be resupplied the addition of this thick material (10-in. thick for 40,000 lb) seems out of the question.

The increase in shield weight required over previous analysis results can be attributed to refined assessment of the following four factors:

1. The differential energy spectrum of the incident electron radiation was expanded to include the flux at low energy levels.
2. The bremsstrahlung flux-to-dose conversion factor were modified in the low energy region.
3. The electron-transmission calculations were slightly modified.
4. The bremsstrahlung dose buildup factors were modified.

These changes were the result of improved and updated techniques of calculation which were implemented to be consistent with current theory. Simplifications, made in the initial development of these computer techniques, were replaced as more exacting analyses became feasible.

Prior to a decision which would commit the MORL to the synchronous mission, the following areas of study should be pursued:

1. The synchronous mission must be defined so that the minimum acceptable laboratory volume can be determined. The present MORL was designed to operate in a moderate radiation environment. Therefore, the radiation environment was not a strong influencing factor on the design. Future configuration studies may result in a reduction of shielded area and thus in a proportionate reduction in the weight of shielding material.
2. The shielding effectiveness of on-board materials such as water and propellant should be determined. This solution would be particularly effective if the livable volume could be significantly reduced.

3. Personal portable shields should be evaluated to determine weight savings as well as possible operational restrictions.
4. The use of laminated shield materials should be evaluated to take advantage of the properties of various materials.
5. The physical task of attaching thick shield material to the laboratory on Earth or in orbit, must be examined to determine the restriction and interactions with other subsystems and experiments.
6. The allowable dose criterion should be reviewed to determine if it could be relaxed for the synchronous mission.
7. The electron flux at synchronous altitude must be better defined.

In addition to the restrictive shield weight required for the synchronous mission, the following three changes to the baseline MORL are required:

1. The EC/LS radiator must be reduced to account for the reduced heat influx at this altitude. This can be accomplished by removing 13 of the 41 circumferential radiator tubes.
2. The communications system must incorporate an S-band system, similar to the Apollo unified S-band system to account for the additional 25 dB space loss at this altitude.
3. A Saturn V launch vehicle is required.

Section 2
PURPOSE

The Phase IIb portion of the MORL study consisted of a series of five sequentially phased tasks.

Task I was primarily concerned with identification of areas of orbital experimentation with a high utilization potential, that is, areas which could be recommended to NASA as offering the highest scientific and technological returns. The scope of Task I was not limited to the identification of MORL missions alone.

Task II addressed the problem of achieving and implementing the orbital objectives identified by Task I analyses. Once again, it was attempted to take a comprehensive overview of the problem by developing a 15-year Mission Plan, in which the respective roles of the Apollo Application Plan (AAP), MORL, advanced logistics systems, and operations in alternate polar and synchronous orbits were derived and identified. As seemed appropriate within the framework of the Mission Plan, experiments were suggested for the AAP and the MORL concepts. The experiments allocated to the MORL were then timelined to yield the Experiment Plan. The Experiment Plan constitutes the best currently available description of orbital experiments and tasks to be accomplished by the MORL in its initial 3 to 5 years of operation.

Task III attempted to assess the responsiveness of the MORL concept specified at the end of the Phase IIa study to the Mission Plan derived in Task II. Assessment of concept responsiveness extended to a study of the MORL's ability to accommodate experiments in the Experiment Plan, as well as the MORL's ability to operate in polar and sychronous orbits. Also, appropriate recommendations were to be made to improve MORL responsiveness to the Mission Plan in general, and MORL accommodation of the Experiment Plan in particular.

Task IV incorporated all design and tradeoff studies necessary to determine the best way of implementing the conclusions and recommendations of Task III. Modification of the Phase IIa concept to include these new features was to conclude Task IV.

Task V was concerned with the evolution of a MORL development and cost plan incorporating the concept revisions carried out in Task IV. System research and technology items necessary to implement these plans in a timely and economical manner were also defined and incorporated into an overall plan.

Thus, Task III is seen to be the connecting link between the two ends of a complete spectrum of analyses designed to refine the MORL mission definition and its responsiveness to that mission. Tasks I and II were grouped on one end of the spectrum; they represent overall requirements and planning analyses in which the MORL is only one of a series of space systems and missions. Tasks IV and V are grouped on the other end of the spectrum; they are designed to improve the MORL's responsiveness to its assigned role within an overall framework of space systems and missions recommended for NASA consideration.

To establish the link between the two ends of the above spectrum, the scope of Task III includes (1) a restatement of mission requirements derived from the overall analyses, (2) a comparison of the performance capabilities of the Phase IIa MORL concept to these requirements, and (3) recommendations derived from this comparison to improve the responsiveness and mission accommodation potential of the MORL.

2.1 MORL MISSION AND EXPERIMENTS REQUIREMENTS

The purpose of the Task Area III report is to assess the responsiveness of the MORL to its assigned missions. Therefore, it is appropriate to restate and summarize the missions and requirements imposed on the MORL.

As derived and justified in the Task I and II reports, the MORL is to have the dual capability of supporting either one of the following programs:

1. A broad based scientific and technological research program designed to develop the basic information, data, and techniques necessary to implement subsequent, highly objective-oriented experimental programs.
2. A highly objective-oriented experimental program designed to fully implement one or more clearly defined scientific, technological, or commercial applications of space stations.

It appears that a broad-based research program can be completed in a low-altitude, low-inclination (30 to 60°) orbit. Subsequent, objective-oriented programs may require operations in polar and synchronous orbits, using one or several MORL modules. Therefore, the capability to operate in polar and synchronous orbits, either singly or simultaneously with other modules, is a design requirement on the MORL.

The initial mission of the MORL is defined as the accomplishment of a broad-based research program in a 50° inclination orbit. The specific experiments comprising this program are those contained in the Experiment Plan. Subsequent, objective-oriented experimental programs cannot be equally defined at this time.

These MORL mission requirements are closely coordinated with the AAP and the availability of an advanced 6- to 12-man logistics spacecraft to support the simultaneous operation of several space stations or the operation of single stations in polar and synchronous orbits.

2.2 APPROACH AND SCOPE

Assessment of MORL responsiveness to the above mission requirements presents a number of conflicting problems. On one hand, the ability of the MORL to accommodate a given group of experiments cannot be conclusively affirmed or denied until integration of the experiment has been attempted by (1) detailed layout drawings, (2) study of specific instrument-subsystem interface and installation problems, and (3) careful time-line analyses of associated crew activities. On the other hand, detailed assessment of a limited time period in the life of the MORL cannot be projected over the entire 3 to 5 year initial MORL mission to guarantee integration of the entire experimental program with the laboratory. Of course, a detailed integration effort, as practiced in the planning of relatively short Mercury-Gemini missions, appears to be neither practical nor necessarily desirable for semipermanent space stations such as the MORL. The effort required is too large, and the results would be continuously invalidated by the necessarily unpredictable course of the experimental program.

For semipermanent space stations, such as the MORL, the most realistic approach to experimental program planning appears to consist of a judicious combination of computer-based experiment integration, with detailed, conventional planning and integration activities limited to small, carefully selected representative portions of the entire mission.

The rapid turnaround capability of the computerized experiment-integration procedure allows expedient replanning of an entire MORL mission in response to changing laboratory conditions and adjustments required by new experimental results. The conventional hand-integration procedure not only spot-checks and verifies the computer results, but points to problems which can be discovered only by use of human judgement and experience. From the point of view of developing an experiment integration methodology for the MORL, it is interesting to note that the limited application of hand-integration is highly useful in developing, and then calibrating, a computer-based experiment-integration tool.

The responsiveness of the MORL to the Experimental Plan has been assessed using the above dual approach. The results of the two approaches are described in Books 1 and 2 of the Task Area III report. Thus, Book 1 considers the responsiveness of the MORL over the entire Experiment Plan and a mission duration of 3 to 5 years; Book 2 examines in more detail the happenings in and around the laboratory during a typical 48-hour period.

Book 1 contains the results obtained from the computer runs made with the Systems Planning and Effectiveness Evaluation Device (SPEED). These runs assess the responsiveness of the MORL to its initial broad-based, R&D mission, as well as the responsiveness of the MORL to an objective-oriented experimental program selected for illustrative purposes only. The responsiveness of the MORL to these experimental programs is discussed in terms of the following: (1) the extent of the utilization of laboratory resources, including the crew; (2) the extent to which resources are critical; (3) the length of time required to complete the experimental program; (4) the momentary mix of active experiments on the laboratory; (5) the impact of subsystem failures and repairs.

To further ensure the ability of MORL subsystems to accommodate experiments, the computer-based study of the subsystem-experiment interface was augmented by a direct comparison of experimental requirements and performance capabilities of subsystems most closely affected by experiments. These subsystems were the (1) Stabilization and Control System (SCS), (2) Environmental Control and Life Support System (ECLS), (3) the Communication System (CS), and (4) the structure and configuration of the MORL. These analyses attempted to assess the ability of the MORL to support R&D, as well as objective-oriented experimental programs. However, as specified in Section 2. 1, the capability to operate in alternate orbits is also a design requirement on the MORL. Therefore, the remainder of Book 1 is concerned with the impact of the polar and synchronous orbital environment on the MORL and its subsystems, including the logistics system. Special emphasis was placed on the study of potential radiation and shielding problems to be encountered in these orbits.

Section 3

ASSESSMENT OF MORL SYSTEM RESPONSIVENESS TO COMPLETE EXPERIMENTAL PROGRAMS

The purpose of this section is to assess the responsiveness of the MORL to two different experimental program types. The first type is a basic research program oriented toward the development of techniques and instruments which will form a scientific and technological foundation for the second type, a highly objective oriented experimental program.

The Experiment Plan, a definition of the initial experiments recommended for the first 2 to 3 years of MORL operations, is an example of the first program. The Experiment Plan must be largely completed before one or more objective-oriented missions can be selected for implementation. This is because, in a sense, this broad-based, R&D program is also a feasibility testing program for key sections of promising objective-oriented programs. However, for an illustrative and preliminary assessment of MORL responsiveness to an objective-oriented mission, a series of 66 experiments, designed to evolve the ways and means of giving operational assistance to Fisheries Production, was selected.

For both experimental program types, MORL responsiveness was assessed over the entire mission and for the entire MORL system. This may be contrasted to assessment of MORL responsiveness to a few selected days of the entire mission and the responsiveness of individual subsystems. A typical 48-hour portion of the Experiment Plan was analyzed in depth to provide insight into the problems arising in the implementation and mechanics of an experiment program. This analysis is discussed in Book 2 (SM-48814) of this report. The detailed responsiveness of the subsystems to the individual experiment requirements is analyzed in Section 5.

PRECEDING PAGE BLANK NOT FILMED.

Perhaps the most significant result of the computer-based portion of MORL responsiveness analysis is the general conclusion that a six-man orbiting research laboratory is adequate in size to carry out a broad-based, R&D program. Particularizing this general conclusion to the MORL concept, the following conclusions can be made:

1. The MORL facility is being used in the most efficient manner possible, that is, the MORL is close to 100% utilization in all its major parameters.
2. The availability of experiment support resources is correctly proportioned. For instance, available experimental crewtime and power are in the correct proportions to each other.
3. The experiment program is being completed in the most expeditious manner possible, that is, no excessive delays and slippages occur in carrying out experiments.
4. Subsystem failures and repairs do not have a significant imapct on the experimental program. However, additional analysis is required to determine the impact of experimental equipment failures.
5. The availability of resources, such as experimental crewtime and power, appears to be correctly matched to the demands of a R&D oriented mission.
6. The ability of the MORL to accommodate larger experimental programs is largely dependent on increasing the crew size from 6 to 9 men. This increase may be particularly important to accommodate the emphasis on specialized skills that appear to be a feature of objective-oriented experimental programs.

In general, availability of adequate crewtime and crew skills appear to be the crucial factors in experiment and mission planning for a semipermanent orbiting research laboratory. Partially because of their close association with crew activities, distribution and installation of experimental equipment and the internal configuration of the laboratory appear to play an equally important role. Availability of electrical power, experimental equipment, and similar resources is, of course, essential but can be assured readily enough to make these resources of secondary importance in mission planning. The following discussion will elaborate on these conclusions.

3.1 RESPONSIVENESS OF THE MORL TO THE EXPERIMENT PLAN

3.1.1 The Experiment Plan

The MORL Experiment Plan is derived and described in detail by the Task II report. The Experiment Plan represents the best currently available definition of the specific experiments to be performed by the MORL in its initial 3-1/2 years of operation. The experiments comprising the Experiment Plan have been derived from two sources, the Data Bank and the Applications Plan.

The Data Bank is a collation of all experiments identified by the MORL, Extended Apollo, AES, and OSSS studies. The Applications Plan was developed as part of the current Phase IIb MORL study and represents an in-depth planning effort to define an oceanographic and meteorological experimental program for space stations.

The Experiment Plan contains only those Data Bank and Applications Plan experiments which were thought to be fundamental to a number of objectives in space and to be contributing to the creation of a broad scientific and technological base for future efforts. For instance, only those Applications Plan experiments concerned with the development and testing of basic instruments and techniques were included in the Experiment Plan. Although these experiments were evolved as part of an oceanographically and meteorologically oriented experimental program, it has been shown that instruments and techniques evolved by them are in fact common to many other Earth-centered scientific and technological objectives.

The Experiment Plan takes maximum advantage of this commonality and emphasizes inclusion of those experiments which appear to benefit several space objectives at one time. The Experiment Plan is, therefore, a reflection of the long-standing view of the MORL as a broad-based orbital R&D facility. Figure 3-1 summarizes some pertinent facts about the Experiment Plan.

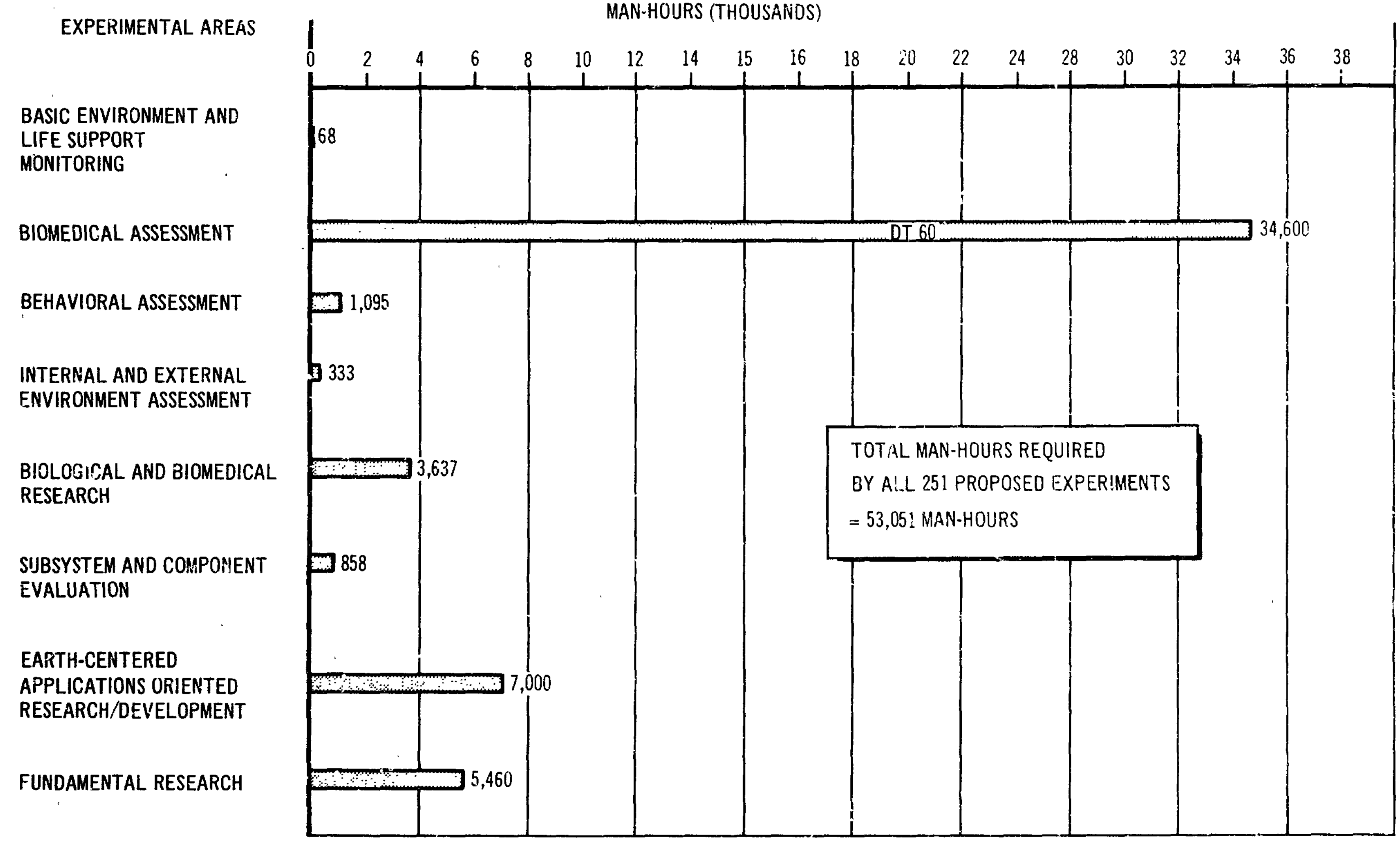


Figure 3-1. Distribution of Man-Hours Between Experimental Areas

As indicated, the Experiment Plan consists of 251 experiments, requiring a total of about 53,000 orbital man-hours for completion. These experiments were input to the SPEED program, to be timelined and scheduled, subject to the performance capabilities of the MORL, including interruptions caused by random breakdown and repair of subsystems. A description of the operation of the SPEED program and a statement of input data used is given in Appendix A of this report.

The discussion below will describe the responsiveness of the MORL, as determined by SPEED, to the broad-based, R&D oriented Experiment Plan. The following criteria will be used to evaluate MORL responsiveness:

1. Efficient utilization of laboratory resources.
2. Timely and rapid completion of the experimental program.
3. The distribution of experimental effort between experiment areas as a function of time, that is, the extent to which a balanced experimental program can be consistently maintained.
4. The effect of laboratory reliability and maintainability on the experimental program.
5. Identification of laboratory resources and subsystems which adversely affect the efficient and timely completion of a balanced experimental program.

3.1.2 Utilization of Laboratory Resources

The measure of design responsiveness of a system must be appropriate to the intended purpose and mission of that system. Thus, in designing delivery systems, such as airplanes, orbital carriers, and launch vehicles, it is quite appropriate to measure the quality of the design by a figure of merit, such as dollars per pound or dollars per ton-mile.

However, an orbital research laboratory (ORL) is not a delivery vehicle, but a facility designed to support orbital experimentation. As is the case with any other facility, its design effectiveness is customarily measured by the achieved utilization of its major resources.

In the case of the MORL, the most important resources are (1) crewtime, (2) crew skills, (3) electrical power, (4) experimental equipment, and (5) logistics systems delivery capability. Many others can, of course, be also named. Experience has shown that the percent utilization achieved of these resources (to be called facility load factors) is an excellent measure of the responsiveness of the MORL design to a particular experimental program.

Facility load factors are calculated by experimental program simulation or scheduling tools, such as SPEED. In essence, SPEED compares the availability of crew time to the crew time demanded by the next experiment eligible to be put on the line. If availability of crew time and all other resources match or exceed the demands of the candidate experiment, the experiment is scheduled.

Very often, however, it will be found that, although most resources are available in adequate amounts, one particular resource is fully utilized. In that case, even though most of the facility resources are under-utilized, no new experiments can be scheduled until an experiment using the one fully utilized resource is completed and taken off the line. For instance, if all crewmen are fully occupied with experiments requiring little power, the power load factor will remain low as long as the crew time load factor is not reduced, that is, one or more crewmen become available to perform experiments which may require more power.

The computer simulation continues in this manner until all experiments have been completed or a preset time (mission duration) has elapsed. An automatic record is kept of the magnitude and timing of changes in the utilization of each resource; that is, the utilization of the resource is calculated as a function of time (utilization profile). By averaging the utilization profile over the entire mission, an average facility load factor may be determined for each resource. Suitable measures of deviation from the average are, of course, also calculated.

Clearly, unequal and unbalanced facility load factors on crew time, power, and other resources reflect a very undesirable situation. For instance, a consistently high crew-time load factor and a consistently low power load factor would indicate that experimental demand conflicts tend to occur predominantly because of inadequate availability of crew time. On the other hand, it would also be apparent that relative to available crew time and the type of experiments assigned to the laboratory, the power system would be too large. For an ORL, this problem may be particularly undesirable in view of the implied additional complexity and weight. Last but not least, an unbalanced design, as indicated by unbalanced facility load factors, implies that by increasing performance capabilities of over-utilized resources, the number of experiments delayed by conflicting demands can be reduced and the completion of the experimental program hastened. In view of the fact that MORL operating costs are \$350 to \$400 million annually, rapid completion of the experimental program is of considerable importance.

Thus, approximately equal and near 100% facility load factors carry the following connotations:

1. The availability of resources (MORL performance parameters) is correctly proportioned relative to each other.
2. The experiment program is being completed as rapidly as is possible with the given size facility.
3. The availability of resources is optimally matched to the general characteristics of the intended experimental program.

It is very important to note the latter condition. Thus, the correct proportion of crew time, power, and other resource availabilities is a function of the type of experimental program to be performed. For instance, in a purely biomedically oriented ORL, the proportion of crew time available for experimentation to electrical power availability should be much higher than in an ORL specialized to experiments in communications.

Maximizing the responsiveness of an ORL involves, therefore, the iterative readjustment of resource availabilities (that is, total crew size, electrical power output, pressurizable volume, and so forth) until all facility load factors are approximately equal and near 100%.

MORL resource availabilities (that is, general performance characteristics) are matched to a broad-based, R&D oriented experimental program. The statistical characteristics of such an experimental program are well described by data presented in the Task I report.

In general, the Experiment Plan scheduled into the MORL facility consists of R&D oriented experiments. The facility load factors indicated in Figures 3-2 reflect the high degree of integration achieved between the MORL facility parameters, on one hand, and the MORL Experiment Plan, on the other hand. These load factors were selected for study because previous MORL studies have isolated them as the most significant from the systems point of view. Particular aspects of these resources relative to the Experiment Plan will be discussed in detail below.

3.1.2.1 Electrical Power

The data shown in Figure 3-2 are based on an 11-kW Brayton cycle isotope power system, and the assumption that of the 11-kW total output 2.55 kW are always available for experimentation. An exception is the loss of power caused by the failure of the electrical power system, or excessive power demands imposed by the failure and repair of another subsystem.

The SPEED simulation results showed that the average electrical power consumption by experiments was only 91 W, or about 3% of the power allocated to experiments. It should be noted that a peak-power consumption of 2,205 W, or 86% capacity, was experienced during the simulated mission. This high peak power requires that the power allocation for experiments should not be reduced. If the housekeeping electrical load of 8,450 W is included in the utilization calculations, then the average overall utilization is 78%, with a peak consumption of 97% of the available 11 kW.

The allocation of 2.55 kW to experimentation is further supported by the occurrence of secondary power peaks at various times during the mission. These power peaks may be identified in Figure 3-3, showing the instantaneous consumption of electrical power at the beginning of each month. The frequency of these snapshot status reports was limited to 1/month, since publication limitations preclude more detailed utilization profiles. The calculation of average load factors, however, is based on an infinitely fine time incrementation permitted by the utilization of special simulation techniquest built into the SPEED program.

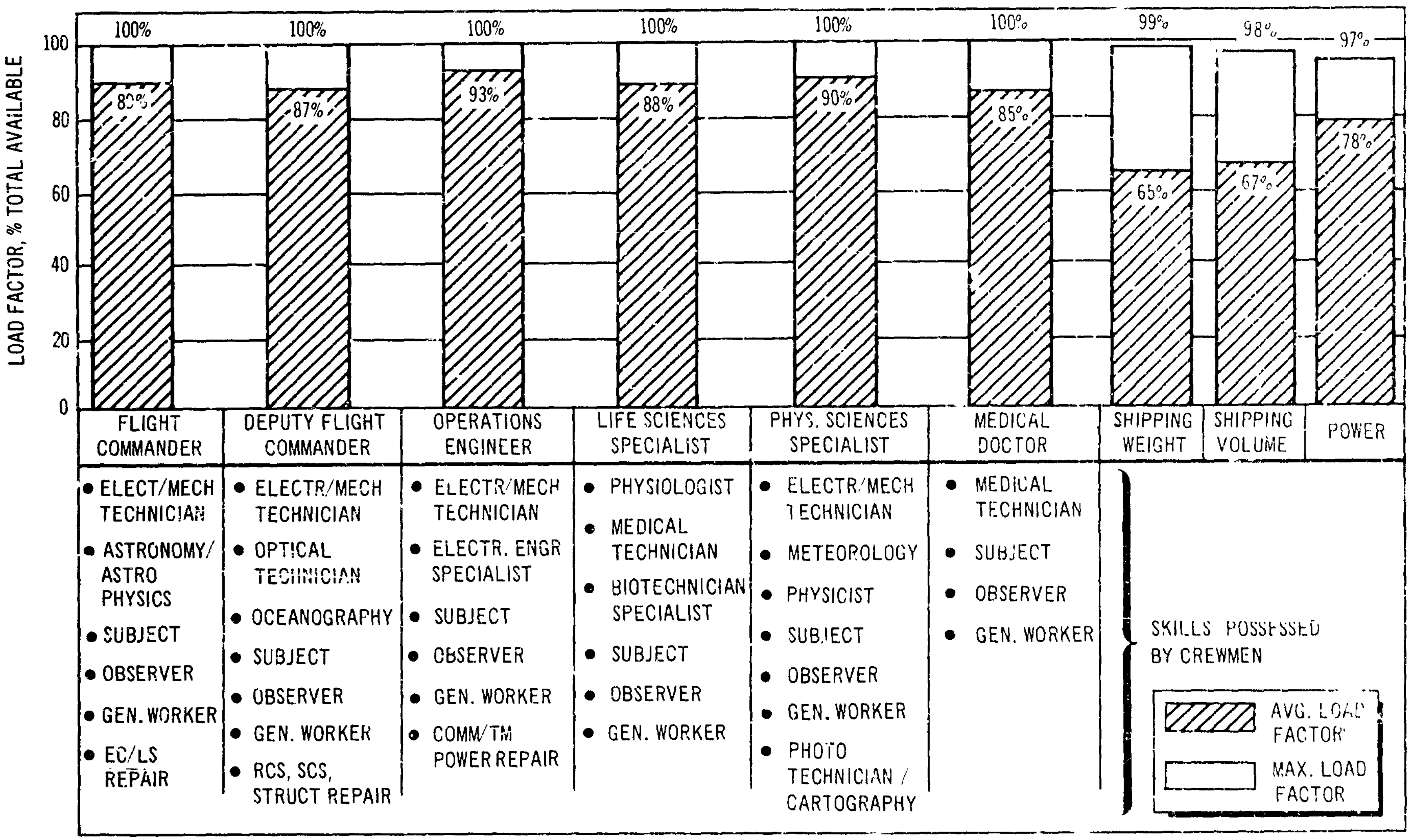


Figure 3-2. MORL Facility Load Factors (32,000-hr. Total Elapsed Time Experimental Program)

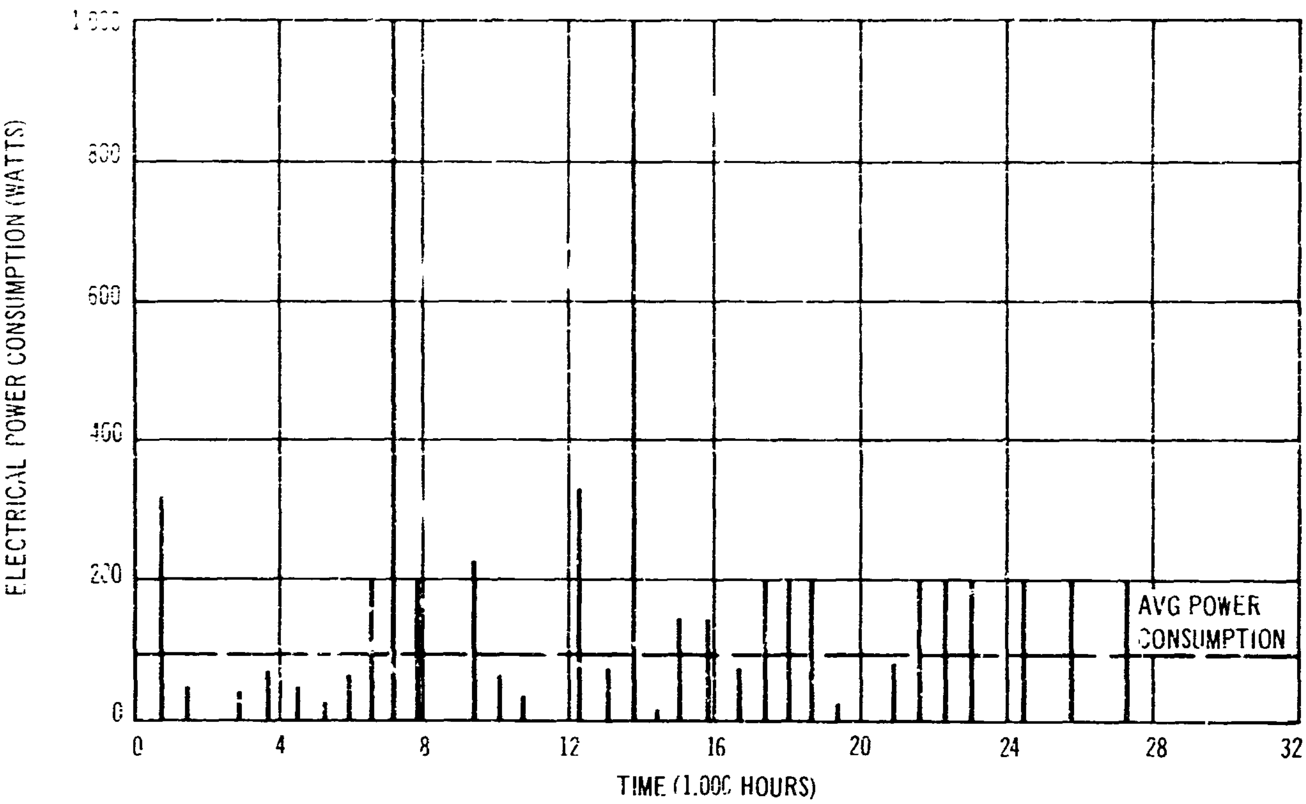


Figure 3-3. Experiment – Electrical Power Consumption

3.1.2.2 Shipping Weight and Volume

Shipping weight and volume measure the cargo delivery capability of the Saturn IB/Apollo logistics system. This logistics system is described in detail in Section 4.3 of this report. In summary, however, the system can deliver a net cargo of 10,000 lb, occupying 1,000 cu ft/flight. Except for the two additional flights required to man the MORL during its first operational year, four such flights are scheduled annually.

Total annual housekeeping (crew consumables, orbit keeping propellant, spares, and so forth) are estimated to be 22,000 lb. The experiments required the delivery of 18,400 lb over the full 3.65-year mission duration. The resulting average shipping weight and volume load factors are 65% and 67%, respectively.

Maximum utilization of logistics delivery capability occurred on the first three logistics launches. The reason for this is that most of the experimental weight had to be delivered at this time. In this worst case condition, weight and volume utilization were 99% and 98%, respectively.

Thus, shipping weight and volume load factors are noted for their moderate average utilization, particularly when compared to the high power and crew utilization achieved. The logistics system load factors can be primarily ascribed to the fact that the flight frequency is not set by cargo requirements, but by biomedical considerations limiting allowable crew stay times on the MORL.

It is currently thought that the average tour of duty should not exceed 180 days. To rotate a 6-man crew using a 3-seat vehicle (Apollo), 4 flights/year are necessary. These 4 flights represent an annual cargo delivery capability of [illegible],000 lb, of which only about 50% can be utilized.

A secondary, but perhaps no less important, reason for the 90-day logistics flight frequency is the flexibility afforded to the experimental program. Thus, it appears very probable that potential increases in allowable crew stay times would be translated into a larger crew size rather than a reduced flight frequency. For instance, an extension of crew stay times to 270 days would allow a nine-man crew and maintain the 4 flights/year.

For purposes of system and subsystem tradeoffs, it is very important to contrast the moderate logistics load factors to the completely utilized capability of the Saturn IB to launch the unmanned laboratory module itself. In terms of tradeoff penalties, exceeding the capabilities of the Saturn IB would mean that the MORL would have to be launched by a Saturn V. On the other hand, additional cargo delivery requirements imposed on the logistics system in no way penalize the total MORL system. If, therefore, a choice can be made which results in the reduction of weight to be launched with the laboratory or the logistics system, the choice should always be made in favor of the initial laboratory launch.

3.1.2.3 Crewmen and Crew Skills

As indicated in Figure 3-2, about 90% of each crewman's day appears to be occupied with experimentation, housekeeping, rest, recreation, exercise, or other activities. The remaining 10% of the 24-hour day represents available, but practically unutilizable time. For instance, the 10% may include the time spent by a crewman in an inactive status because the other five men have completely utilized all available power, and there is no experiment eligible to start which does not require some power. Many detailed examples of such forced inactivity are given in Book 2 of the Task III report.

It appears that the approximately 90% load factor evolved for each member of the crew is the maximum practical. The crew, therefore, can be said to be utilized to the fullest extent possible. However, in previous MORL studies, the availability of crew skills has been found to be of equal if not greater importance than gross crewtime.

Therefore, the responsiveness of the current MORL crew skill mix to the Experiment Plan has been studied with particular concern. The skills currently specified for each of the six crewmen are shown in Figure 3-2. As can be seen, several men may possess the same skill, that is, all men can be general workers.

The availability of skills and their utilization are shown in Figure 3-4. As indicated, there are six men possessing the skill called general workers. On an average, 5.3 men with this skill are seen to be occupied. It is to be noted that this does not imply that on an average 5.3 men are actually exercising the skill of a general worker. For instance, one of these men may be functioning as an astronomer. Because, however, a man is assumed to be capable of working on only one task at a time, his assignment to an astronomer's tasks effectively implies that his skill as general worker is also utilized, that is, unavailable.

Because of this peculiarly interdependent nature of the resources called crew skills, it is perhaps more meaningful to study that fraction of total crew skill availability which is left unutilized. Returning to the above example, it may be seen that on an average 0.7 men with the skill of a general worker are unoccupied and unutilized. For maximum MORL crew efficiency, the nonutilization factor should of course be small. Figure 3-4 certainly indicates this to be the case.

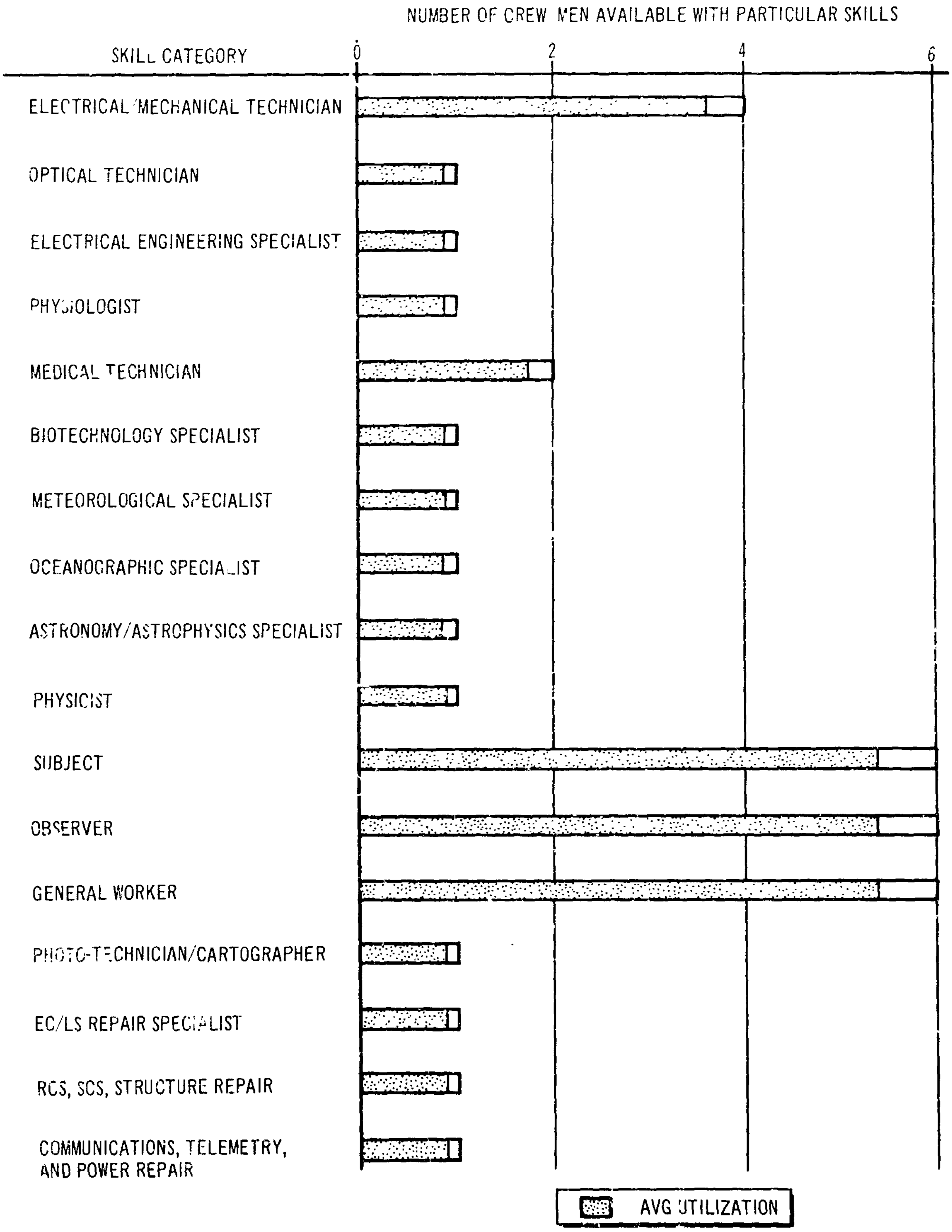


Figure 3-4. Utilization of Skills (6-Man Crew)

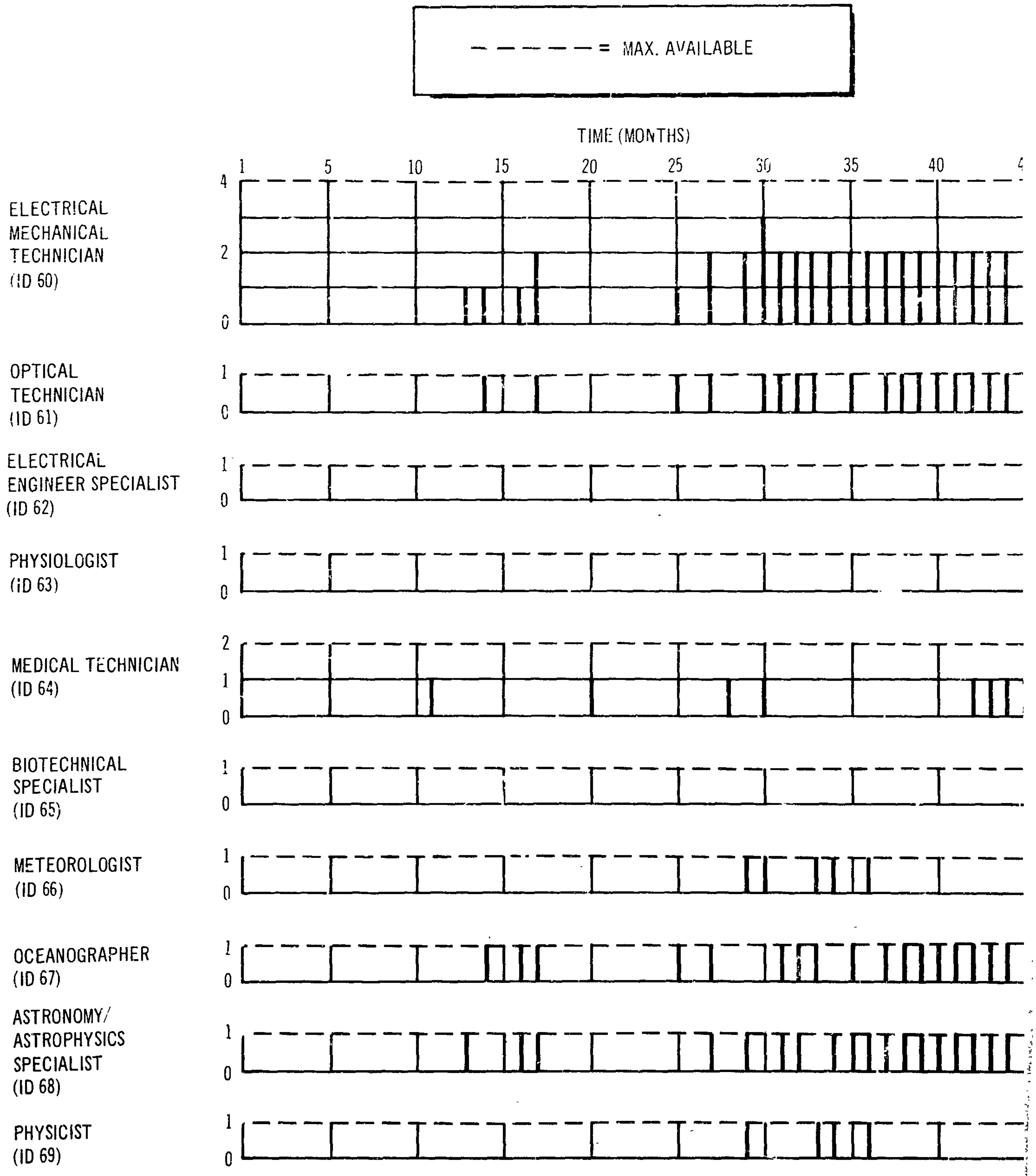
With the monthly snapshot technique employed to indicate peak power loads, similar snapshots were taken of crew skill utilization as a function of time. The availability (that is, nonutilization) of each skill is shown in Figure 3-5. As indicated, all skills tend to be heavily utilized in the first half of the program. As will be shown below, the second half of the program consists of experiments which tend to emphasize the general skills (observer, subject, general worker and so forth) and tend to de-emphasize the utilization of more specialized skills. The utilization of skills as a function of time agrees, therefore, with the changing complexion of the experimental program.

3.1.3 Time Required to Complete the Experiment Plan

The MORL Experiment Plan is comprised of 251 experiments, totalling about 53,000 man-hours. Because a six-man MORL makes available 16,700 experimental man-hours/year, with a perfect [illegible]% utilization of crew time, the Experiment Plan requires a minimum of 3.16 years to complete. Figure 3-6 indicates that experiments are being actually completed at a nearly constant rate of about 100/year.

At about 20 to 21,000 hours of lapsed time (that is, somewhat over 2 years), this rate drops off significantly. The reason is that at this time essentially all but the biomedical-behavioral experiments are completed. At the end of 3.65 years (32,000-hours of lapsed time), 10 of these extremely long duration experiments were still incomplete. All of the other 241 experiments, however, have been completed.

Reference to the Experiment Plan contained in the jacket of this report indicates that conflicting demands placed by experiments on laboratory resources can be resolved with only minor slippages and experimental delays. The extent to which this has been achieved is indicated by the triangular mark on each horizontal bar showing an active experiment. The triangular mark denotes the position of the middle cycle of a multicycle experiment. (Publication limitations precluded the identification of each individual cycle of a multicycle experiment; the solid bar should, therefore, be interpreted as an experiment on board, but not necessarily continuously on-line.)



- - - - - - = MAX. AVAILABLE
TIME (MONTHS)
1
5
10
15
20
25
30
35
40
ELECTRICAL MECHANICAL TECHNICIAN (ID 60)
OPTICAL TECHNICIAN (ID 61)
ELECTRICAL ENGINEER SPECIALIST (ID 62)
PHYSIOLOGIST (ID 63)
MEDICAL TECHNICIAN (ID 64)
BIOTECHNICAL SPECIALIST (ID 65)
METEOROLOGIST (ID 66)
OCEANOGRAPHER (ID 67)
ASTRONOMY/ ASTROPHYSICS SPECIALIST (ID 68)
PHYSICIST (ID 69)

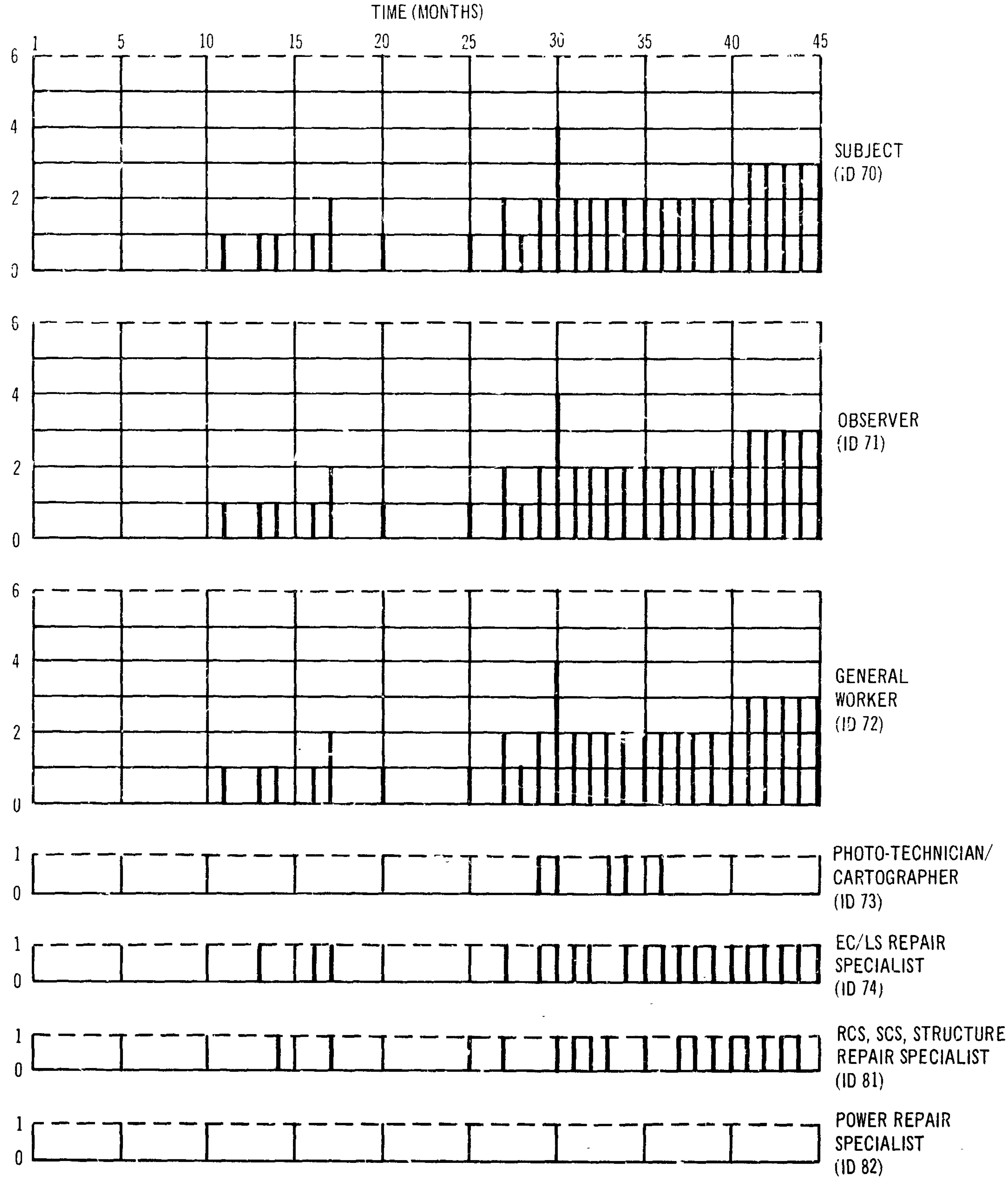


Figure 3-5. Crew Skill Resource Availability

29

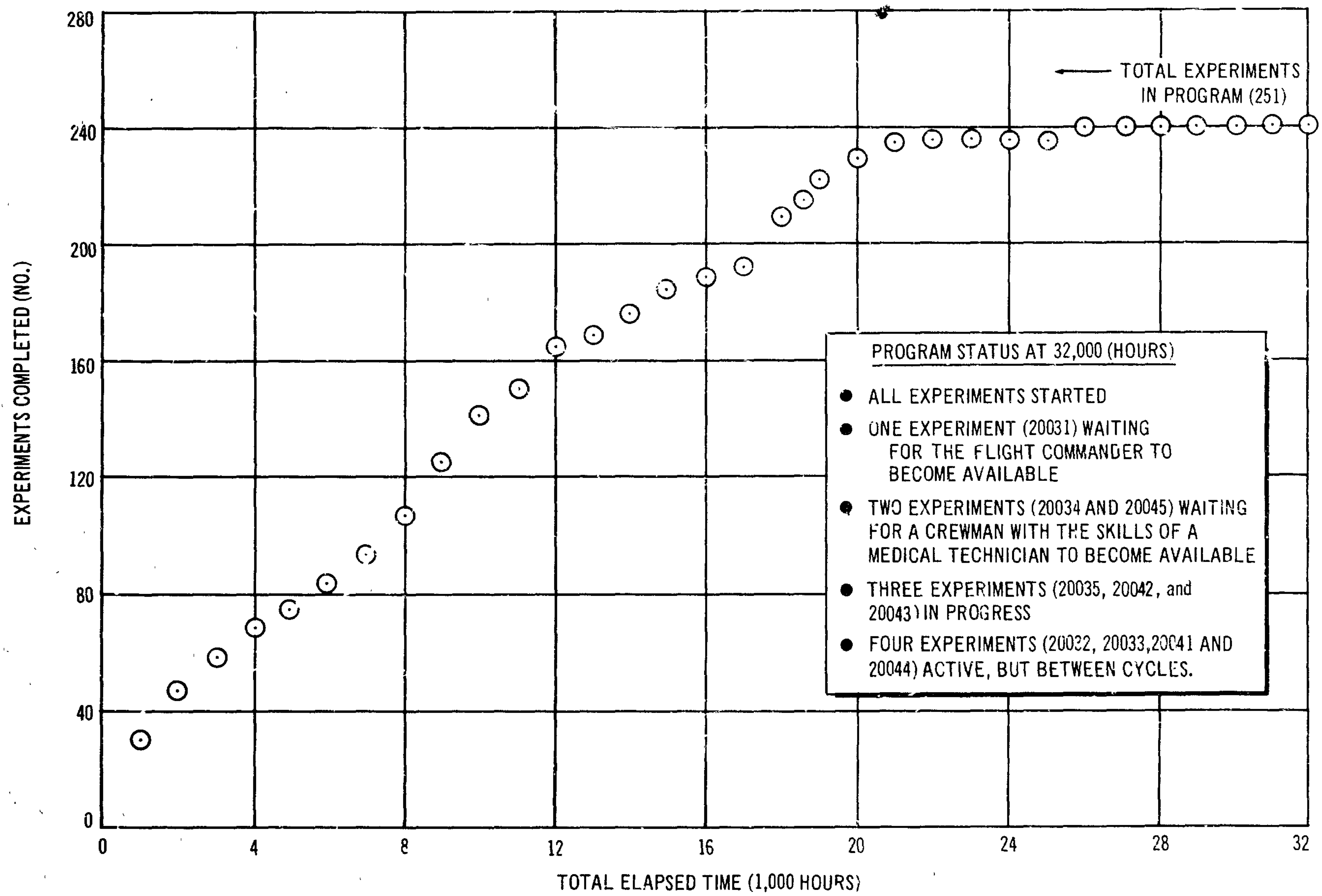


Figure 3-6. Experimental Program History

An inspection of the Experiment Plan indicates that the middle-cycle tends to be positioned in the geometric center of each of the bars. This, of course, indicates that cyclic experiments are performed regularly. However, some experiments (Experiment 233, for instance) could be scheduled at the time shown only by performing some experiment cycles at irregular intervals. In no case does this influence the quality of data returned from the experiment.

It may be concluded, therefore, that a six-man MORL can implement a R&D oriented experimental program in a timely manner.

3.1.4 The Composition of the Experiment Plan as a Function of Time

One of the most significant conclusions allowed by this computer-based study of MORL responsiveness to the Experiment Plan is that a six-man laboratory has adequate capability to maintain at all times a balanced, broad-based R&D program. This is made apparent by inspecting the Experiment Plan and noting that within a few weeks after laboratory launch, experiments in every one of the major experiment areas are in progress. Furthermore, a balanced program can be maintained throughout the mission until the list of experiments to be performed begins to be exhausted.

Table 3-1 and Figure 3-7 indicate the momentary composition of the program with time. Only approximately 25% of all experiments active at the beginning of the program are biomedically and behaviorally oriented. It should be noted, however, that all experiments in this category are started soon after laboratory launch. The relatively small fraction of biomedically and behaviorally oriented experiments in the early portions of the Experiment Plan does not, therefore, indicate that this experimental category is not emphasized, but rather that a strong effort is being made to ensure an early start of as many other types of experiments as possible.

This was achieved by an experiment scheduling philosophy built into SPEED, which places heavy emphasis on maximum utilization of MORL resources. In general, resources were allocated to experiments in order of priority. This order of priority is indicated by the order in which basic experimental areas are listed on the Experiment Plan. Thus, life-support monitoring

Table 3-1

NUMBER OF ACTIVE EXPERIMENTS DEVOTED TO EACH EXPERIMENT AREA

Experimental Areas	Elapsed Time Thousands of Hours: 0		2		4		6		8		1 Year 10	12		14		16		20		2 Years 22		24		26		28		3 Years 30		32	
Basic Environment and Life Support	2	2	2	2	2	2	2	2	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomedical Assessment	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	10	10	10	10	10	10	10	10	10	10	10	10
Behavioral Assessment	24	24	24	24	24	24	24	22	17	1	5	4	3	3	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Internal and External Environment Assessment	5	6	5	5	5	5	5	4	2	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Biological and Biomedical Research	14	16	13	12	12	12	13	13	13	13	9	9	9	9	9	9	9	9	7	4	4	2	2	1	1	1	1	1	0	0	0
Subsystem and Component Evaluation	19	15	10	8	8	8	7	4	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Earth Centered Applications Research	30	19	22	25	23	24	19	20	18	17	16	21	14	12	19	19	15	12	9	3	4	1	1	2	2	1	0	0	0	0	0
Fundamental Research	22	16	13	11	8	9	1	1	8	6	4	2	2	2	2	2	2	2	2	2	1	0	0	0	0	0	0	0	0	0	0

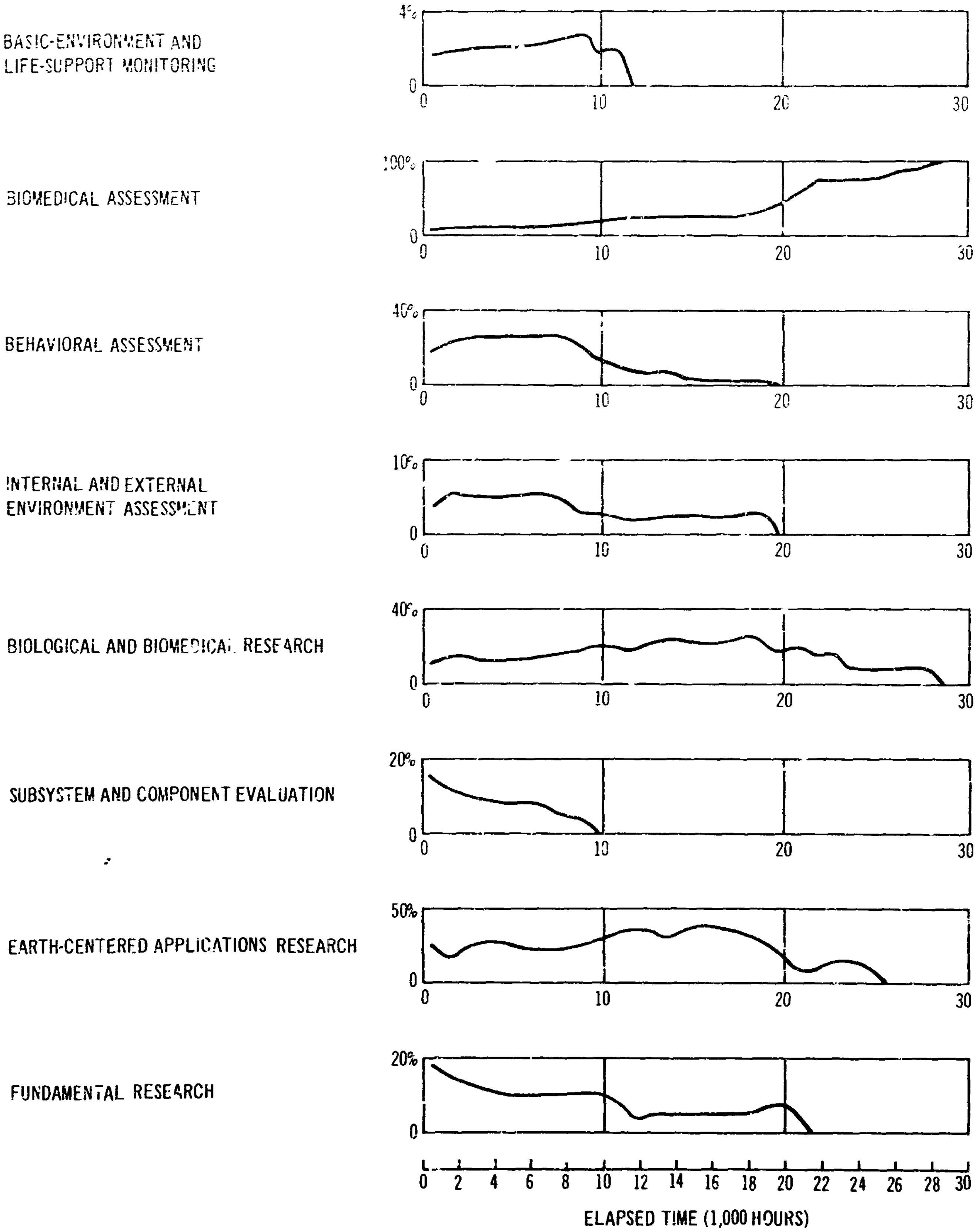


Figure 3-7. Percent of Active Experiments Devoted to Basic Experimental Areas

experiments have the highest priority, biomedical the second highest, and fundamental research experiments the lowest. No priority distinctions are made within each experiment area. On the other hand, a high priority rating merely ensures an experiment first call on currently available resources; it does not force scheduling over lower priority experiments.

For instance, consider Experiments A, B, and C with power requirements of 3, 1, and 0.8kW, respectively. Furthermore, assume that A has a higher priority rating than B, and that B has a higher priority than C. In this example, the SPEED computer program stores all three experiments in a set of experiments called "experiments waiting for power". There are as many such sets as there are resources, although some of these sets may, of course, be empty. Whenever an experiment is completed, the resources used by that experiment are correspondingly increased. When that happens, the sets of experiments waiting for resources are searched for experiments that could be started. Returning to the above examp assume that an experiment has just been completed and the available power has gone up to 1.5 kW. As soon as the power increase has been noted, the set of experiments waiting for power is searched for experiments that could be started. Because A has the highest priority rating, it has first call on resources. However, it will not be scheduled because it requires 3 kW, when only 1.5 kW are available. Next, because Experiment B has the second highest priority, an attempt will be made to schedule it. Because the 1.5 kW is adequate to cover its requirements of 1 kW, the attempt will be successful. The power then remaining available is 0.5 kW, so that Experiment C cannot be scheduled. Thus, at the end of the transaction, the set of experiments waiting for power includes Experiments A and C.

For a complete understanding of the Experiment Plan, it is therefore important to note that priority ratings are actually only preference ratings and that a low-priority experiment can start before a high-priority experiment. There are many examples of the results of this scheduling philosophy on the Experiment Plan. As will be shown below, the main advantage of following this philosophy is that the laboratory is utilized to the fullest extent possible.

There are cases when this scheduling philosophy must be overridden and one experiment must be forced to start before another. An example of such a situation is given by Experiments 1501 and 501. Experiment 1501 is the setup and calibration task that must precede the start of Experiment 501. By use of suitable inputs, this logical and sequential relationship can be enforced over all other considerations pertaining to the start of experiments, including resource availabilities and preference ratings.

The combined use of the latter type of inputs and of the priority and preference ratings has, in fact, been sufficient to ensure the balanced and logical sequence of experiments shown on the Experiment Plan. Thus, early start of such experiments essential to crew safety as life support, biomedical, and behavioral experiments is combined with the near-simultaneous start of experiments in other areas of investigation. On the other hand, the early start of these experiments and their generally short duration combine to increase the percentage of active experiments devoted to biomedical and biological research as the Experiment Plan advances toward the 3-year mark. Thus, the gradual completion of all but a few very long-duration (primarily biomedical) experiments can be observed.

3.1.5 Effect of Subsystem Failures

As described in Appendix A, Section 1, to this report, the mathematical model incorporated into the SPEED program had provisions to reflect the effect of random subsystem failures on the Experiment Plan.

In general, the high reliability and maintainability incorporated into the MORL design appears to have resulted in an experimental program essentially undisturbed by subsystem failures. As indicated in Table 3-2, there were a total of 21 subsystem failures in the 3.65 years of simulated time. The total downtime on the failed subsystems was only 327.9 hours. In all, there were 123 experiment interruptions during the simulated mission.

It is to be noted that three subsystems (Electrical Power, RCS, and Structure) had mean time between failures (MTBF's) large enough to avoid failures

Table 3-2

SUBSYSTEM PERFORMANCE ANALYSIS
(32, 000-HOUR ELAPSED-TIME MISSION)

Subsystem Name	Failures (No.)	Total Downtime (Hour)	Total Time in Emergency Conditions (Hour)	Experiments Interrupted/Failure (No.)
Electrical power	None	0	0	0
EC/LS	6	21.72	15.71	3
SCS	7	244.74	76.74	7
Communication telemetry/ data Processing	8	61.41	45.40	7
RCS	None	0	0	0
Structure	None	0	0	0

Note: Emergency Condition is defined to be a failed subsytem which cannot be repaired because of lack of necessary resources.

entirely. A reevaluation of these MTBF's may, therefore, alter the above conclusions somewhat through the introduction of lower MTBF's and, therefore, more failures.

It is also to be kept in mind that the above results refer only to subsystem associated experiment interruptions. Thus, failures of the experimental equipment itself were not considered. Therefore, the above results should only be interpreted as an order-of-magnitude assessment of the realibility-experimentation interface. The tool for a complete assessment is now existing in the form of the SPEED program. Generation of suitable input data, a major effort, remains the sole obstacle.

3.1.6 Assessment of MORL-Experiment Interface Limitations

From a computer-based (SPEED) assessment of MORL responsiveness to the Experiment Plan, the major limitation on the capability of MORL to perform experiments resides in the difficulty of making available a crewman with the required skills at the time the demand for it occurs.

Figure 3-8 shows major MORL resources (equipment, crewmen, crew skills, subsystems, and so forth) which at one time or another during the simulated mission caused experiments to be delayed. Other resources which never caused a delay are not shown.

Reference to Figure 3-8 indicates that crew skill shortages are the predominant cause of experiments waiting. Thus, an average of 5.6 experiments were waiting for a man with the skills of an electromechanical technician to become available. By contrast, only 0.75 experiments could be classed as waiting for electrical power before they could get scheduled.

In addition to the skills of an electromechanical technician, medical technician, meteorologist, and observer seem to be in short supply. For these, the latter skill is particularily indicative of the limitations of a six-man crew.

Within the context of this analysis, the observer skill does not imply a particularly well trained observer, merely somebody to observe or watch a simple and uncomplicated instrument or phenomenon. Thus, all six crewmen

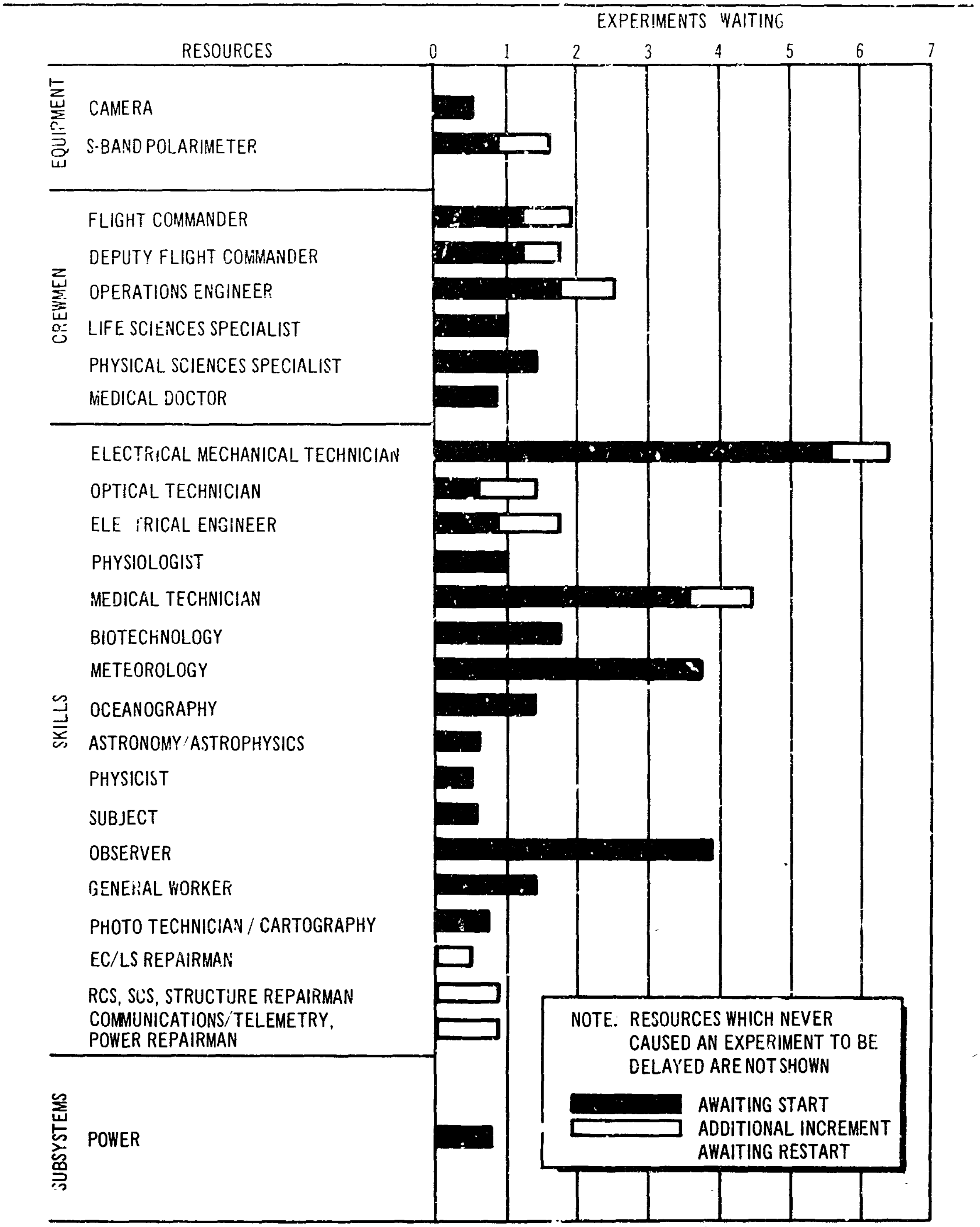


Figure 3-8. Average Number of Experiments Awaiting a Resource
(Effect of Resource Deficiencies Caused by Subsystem Failures Included)

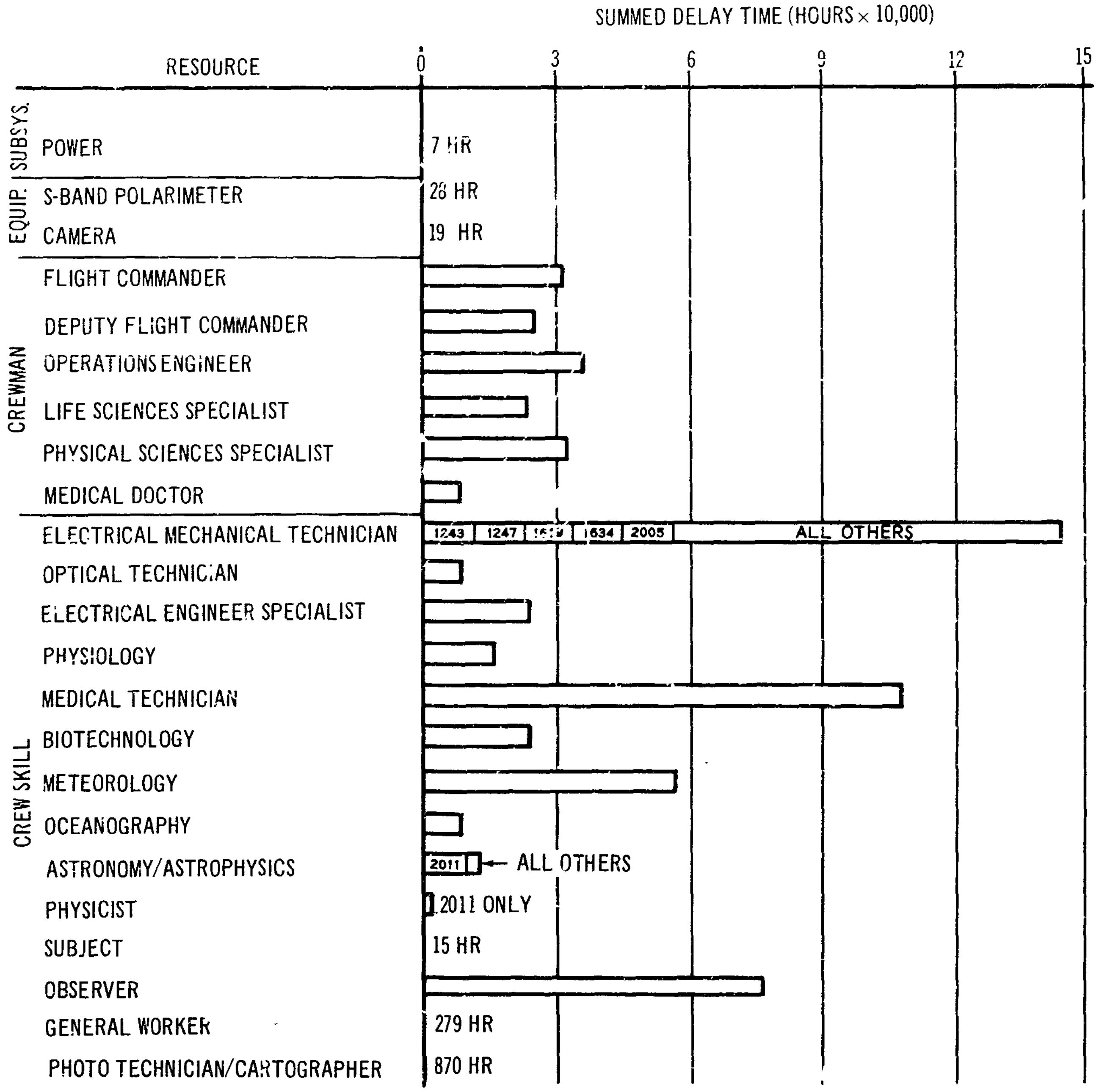
have the skills of an observer. Therefore, the shortage of this particular skill is an indication of an occasional shortage of crewman or gross crew time available for experimentation.

Figure 3-9 further confirms the limiting effect of crew skills. This figure shows the final delays caused by a given resource summed over all experiments which were delayed by that resource. For instance, if Experiment A is delayed twice, once for 1 hour and once for 2 hours, by a shortage of power, and Experiment B is delayed once for 10 hours. Figure 3-9 would show a total delay of $1 \cdot 1 + 1 \cdot 2 + 1 \cdot 10 = 13$ experiment-hours chargeable to power shortage. The unit of experiment-hours of delay is similar to man-hours and has been found to be a significant, although artificial measure of the extent of delays caused by resource shortages.

It is interesting to note that the four crew skills mentioned above are once again found to be the major contributors to experiment delays. It is also important to note that one-half of the total experiment-hours of delay chargeable to the shortage of a man with the electromechanical technician skill can be ascribed to five experiments--No. 1243, 1247, 1619, 1634, and 2005.

This observation brings up the point that, in actuality, the MORL and its Experiment Plan form a single system. Construction and optimization of this system is one way of looking at the well-known experiment integration problem. However, recognition of this will also make it very clear that it is not possible to talk about the limitations of MORL without talking about the limitations of the Experiment Plan.

For instance, inspection of the experiment briefs describing the above experiments will indicate that the requirement for the electromechanical technician skill is not an absolutely necessary one but is, in fact, somewhat arbitrary and artificial. The limitation indicated by the results shown in Figure 3-9 may, therefore, be more properly assigned to the experiments rather than the MORL. Conversely, the limitation may be best removed by experiment redesign and not by alterations of the laboratory design. This is, of course, not an infrequent case in experiment integration. It is useful to note, however, that SPEED-type programs can readily pinpoint such experiments before their redesign becomes a difficult and expensive effort.



NOTE

EXPERIMENTS HEAVILY IMPACTED BY RESOURCE DEFICIENCIES ARE SPECIFICALLY IDENTIFIED.	HOURS SUMMED OVER ALL EXPERIMENTS UNLESS OTHERWISE NOTED	RESOURCES WHICH NEVER CAUSED AN EXPERIMENT TO BE DELAYED ARE NOT SHOWN

Figure 3-9. Relative Contribution of Resource Deficiencies to Experiment Delays

The identification of critical paths through the Experiment Plan is a further example of limitations arising out of experiment design. Portions of the Experiment Plan (those derived from the Applications Plan) have a PERT-type network structure indicating logical predecessors and successors to each experiment. This network (Figure 3-10) has been input to SPEED and has been timelined without violation of the implied logical relationships.

As computed by the SPEED program, the critical path through the Applications Plan (that is, networked) portions of the Experiment Plan is defined by the sequence of Experiments 1501, 501, 1601, 601, 1719, 719, and 769. This sequence is concerned with the determination of space effects on IR and UV detectors, their cooling problems, and their eventual use in cameras. A number of other experiment chains of nearly equal length exist. Relaxation of certain requirements contained in the experiment briefs could, therefore, possibly be used to shorten the logical minimum duration of this portion of the experimental program by several thousand hours of lapsed time.

3.2 RESPONSIVENESS OF THE MORL TO AN OBJECTIVE-ORIENTED EXPERIMENTAL PROGRAM

As stated in Section 2.1, the MORL must be capable of supporting a highly objective-oriented as well as a broad-based R&D oriented experimental program. Until the initial R&D mission is completed, it is not feasible to select objective-oriented experimental programs for the MORL, except for illustrative purposes.

To assess the responsiveness of the MORL to an objective-oriented experimental program, it was assumed that the objective selected would be the evolution of all necessary techniques and instruments necessary to bring to operational status a program of routine assistance to Fisheries Production. It is to be noted that this objective definition carries the following connotations:

1. Only those experiments with a direct bearing on the stated objective will be performed, that is, experiments with no clear relationship to the objective will be excluded from the experimental program.
2. The experimental program is limited in scope to the evolution of the means and methods for giving operational assistance to Fisheries Production. Although this may include prototype operations with

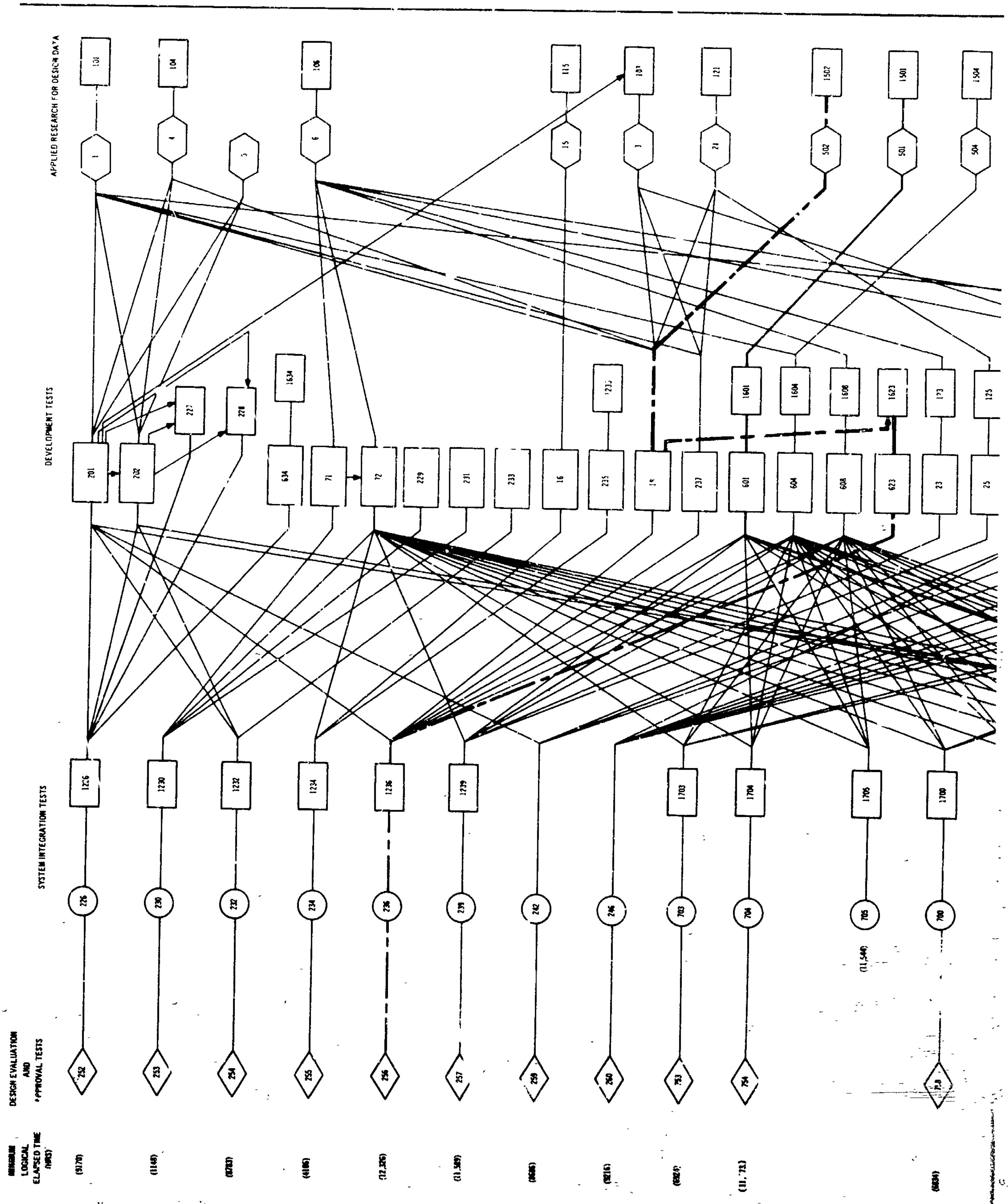
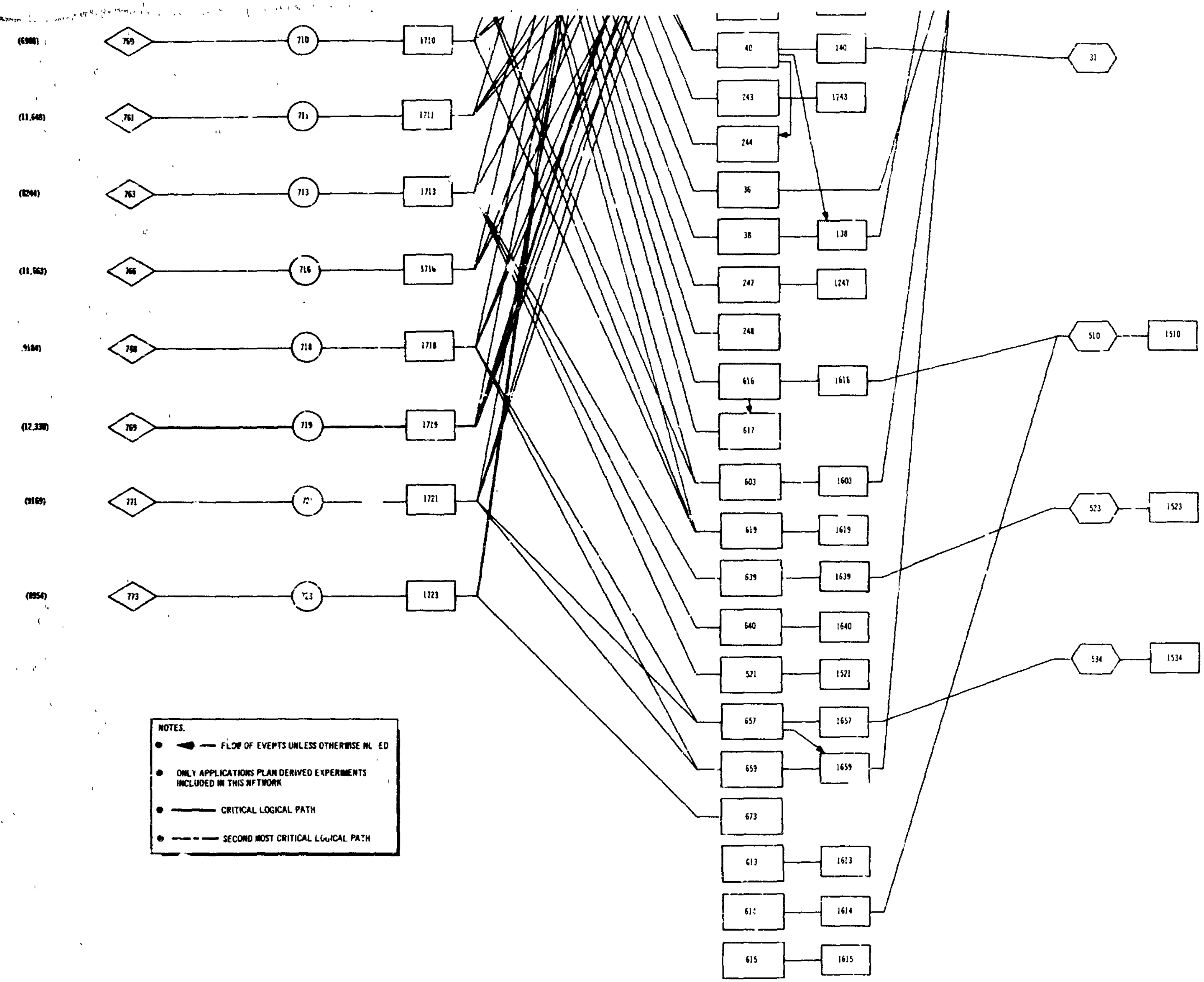


Figure 3-10. Experiment Plan (Events Network)



(6988)
(11,648)
(8244)
(11,563)
9184)
(12,330)
(9169)
(8954)
759
761
763
766
768
769
771
773
710
713
716
718
719
1710
1711
1713
1718
1719
1721
1723
40
243
244
36
38
247
248
616
617
603
619
639
640
521
657
659
673
613
615
140
1243
138
1247
1616
1603
1619
1639
1640
1521
1657
1659
1613
1614
1615
31
510
523
534
1510
1523
1534
NOTES.
FLOW OF EVENTS UNLESS OTHERWISE N ED
ONLY APPLICATIONS PLAN DERIVED EXPERIMENTS INCLUDED IN THIS NETWORK
CRITICAL LOGICAL PATH
SECOND MOST CRITICAL LOGICAL PATH

breadboard equipment, actual operational use of the means and methods evolved by the orbiting research laboratory would be implemented by either manned or unmanned space stations, as deemed appropriate at the right time.

Both of the above points may be taken as complementary definitions of objective-oriented experimental program.

An experimental program oriented toward the objective of assistance to Fisheries Production has been defined within the oceanography portion of the Applications Plan discussed in Reference 2. The program consists of 66 experiments, all of which were related in the PERT-type predecessor-successor relationship shown in Figure 3-11. The experiment task levels proceeded from the necessary applied research, through development tests of components and techniques, and their integration and design evaluation, to an operational capability in the area of Fisheries Production.

To assess MORL responsiveness to an objective-oriented experimental program, the entire network of 66 experiments was input to the SPEED program. The following evaluation criteria were used:

1. Efficient utilization of laboratory resources.
2. Timely and rapid completion of the experimental program.
3. Identification of laboratory resources which adversely affect the efficient and timely completion of the experimental program.

The laboratory resource definitions were identical to those used to study the Experimental Plan. However, a crew complement of nine men (providing 60.3 experimental man-hours/day as compared to 46 man-hours/day from a six-man crew) was assumed to provide more latitude in postulating skill mixes for parametric study purposes.

As in the case of the broad-based R&D oriented Experimental Plan, the most important laboratory resource was gross crew time and the crew skill mix.

Three computer runs were made to study the skill combinations shown in Table 3-3.

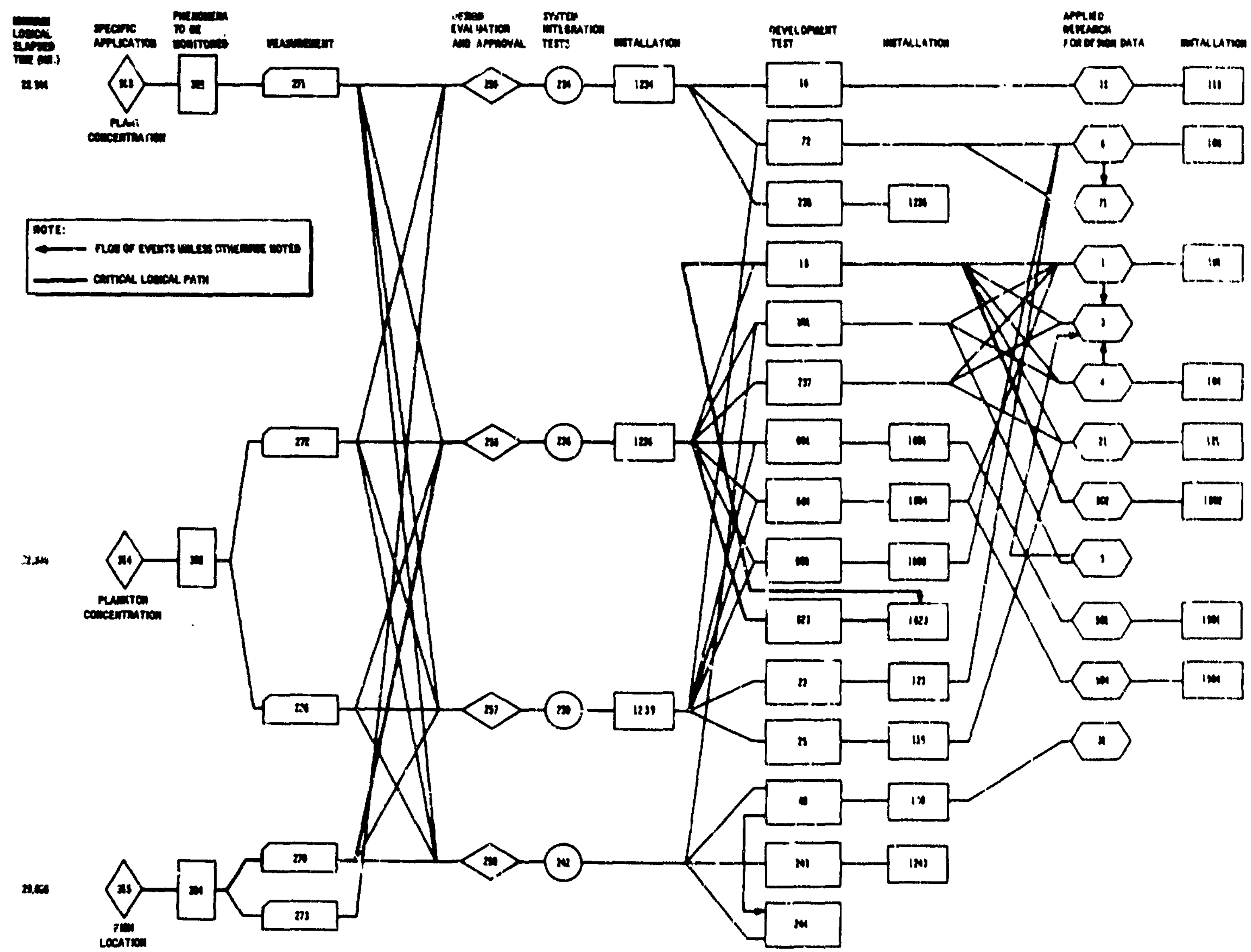


Figure 3-11. Fisheries Production (Events Network)

Table 3-3

SKILL COMBINATIONS FOR THE FISHERIES PRODUCTION ORIENTED EXPERIMENTAL PROGRAM

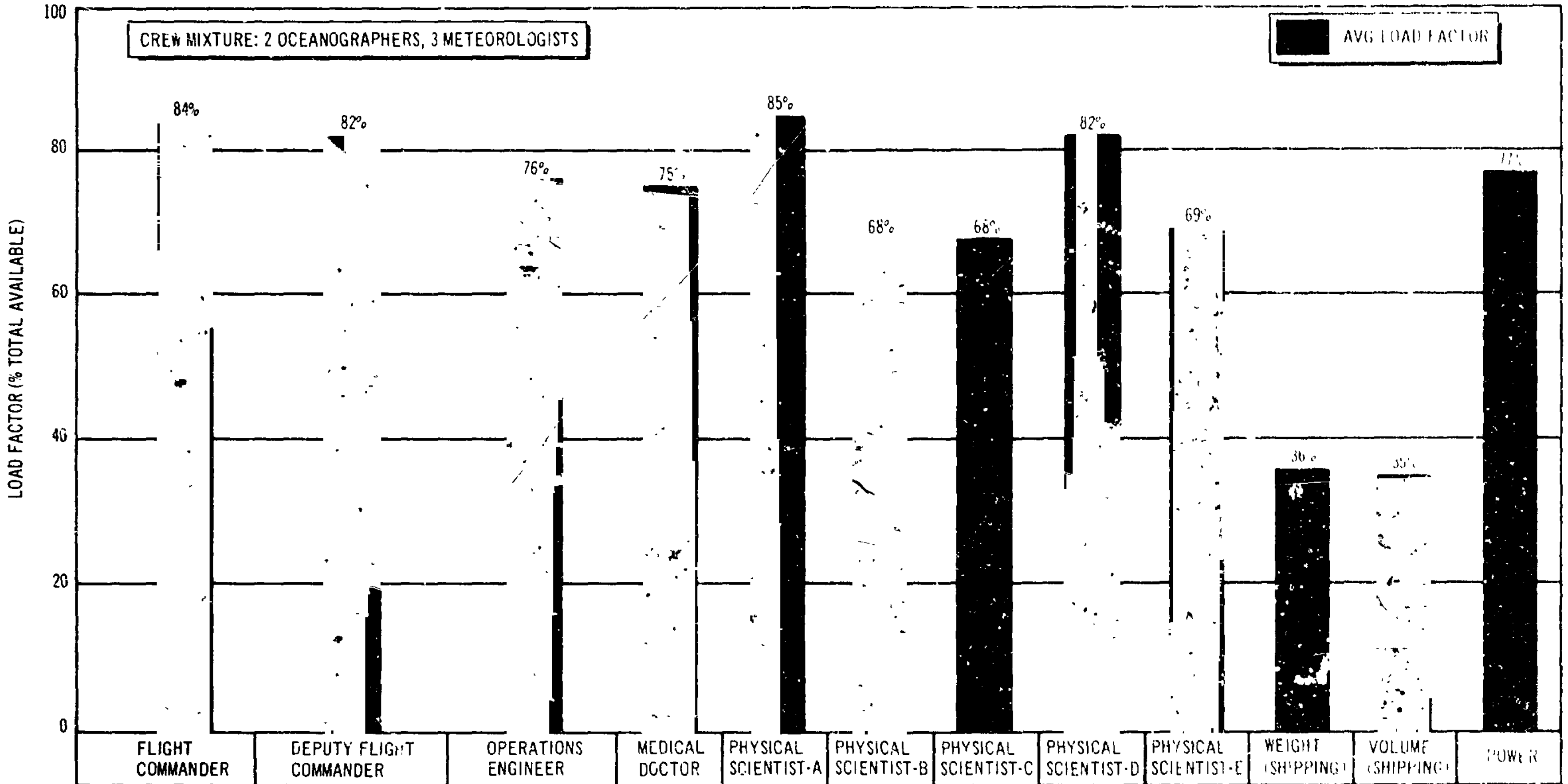
Run (No.)	Men With Oceanographer Skills (No.)	Men With Meteorologist Skills (No.)	Men With Other Skills (No.)
1	2	3	4
2	3	2	4
3	4	1	4

The first skill combination was selected on an intuitive basis by inspection of the experiments comprising the Fisheries Production Experiment Plan. The other two combinations were selected by iterative review of SPEED outputs, and evaluated by means of the three criteria stated above. The following observations can be made as a result of the three SPEED runs.

3.2.1 Utilization of Laboratory Resources

Figures 3-12 to 3-14 show facility load factors for the three computer runs simulating an experiment plan oriented toward development of operational assistance to Fisheries Production. These figures are good indicators of the complexity of the laboratory/experiment interface.

The utilization of the crewmen appears to follow the principle of equalizing the workload on all the individuals. This is very desirable and is consistent with the view that a well designed facility must be equally utilized in all of its major parameters. Specifically, this condition is shown by examining the utilizations of Physical Scientists A and D (both oceanographers). In the first run they exhibit utilizations of 85 and 82%, respectively, as seen in Figure 3-12. As the skill of Physical Scientist C is changed from that of meteorologist to that of oceanographer in Run 2 (Figure 3-13), the utilization of Physical Scientist A remains unchanged while that of Physical Scientist D only reduces to 77%. Thus, the addition of another oceanographer did not reduce the work of the two original oceanographers greatly. In fact, the utilization of the additional oceanographer was 77% in Run 2. This means that replacing the meteorologist skill with that of an oceanographer resulted in more oceanography tasks being accomplished earlier, rather than in a



FLIGHT COMMANDER	DEPUTY FLIGHT COMMANDER	OPERATIONS ENGINEER	MEDICAL DOCTOR	PHYSICAL SCIENTIST-A	PHYSICAL SCIENTIST-B	PHYSICAL SCIENTIST-C	PHYSICAL SCIENTIST-D	PHYSICAL SCIENTIST-E	
• MECHANICAL/PHOTO TECHNICIAN • OBSERVER • GENERAL WORKER • EC/LS REPAIR SPECIALIST	• MECHANICAL/PHOTO TECHNICIAN • MECHANICAL ENGINEER/OPTICS • OBSERVER • GENERAL WORKER • RCS, SCS, STRUCTURE, REPAIR SPECIALIST	• ELECTRICAL ENGINEER/ MECHANICAL • OBSERVER • GENERAL WORKER • C&T, POWER REPAIR SPECIALIST	• OBSERVER • GENERAL WORKER	• OCEANOG-RAPHY • OBSERVER • GENERAL WORKER	• METEO-ROLOGY • OBSERVER • GENERAL WORKER	• METEOR-OLOGY • OBSERVER • GENERAL WORKER	• OCEANOG-RAPHY • OBSERVER • GENERAL WORKER	• METEO-ROLOGY • OBSERVER • GENERAL WORKER	SKILLS POSSESSED BY CREWMEN

Figure 3-12. MORL Facility Load Factors (Experiments and Life-Support Operations)–(a)

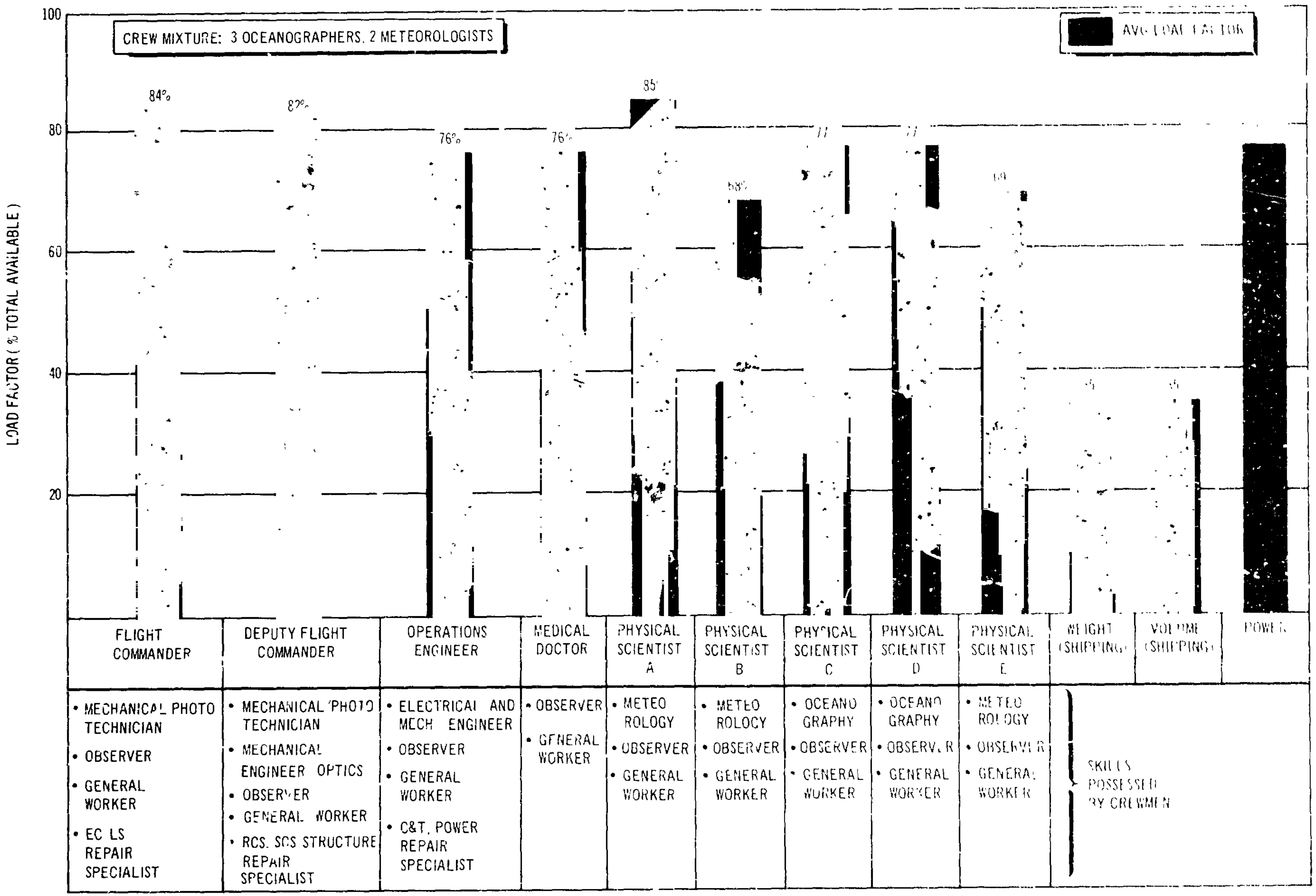


Figure 3-13. MORL Facility Load Factors (Experiments and Life-Support Operations) – (b)

reduction in the utilization of the original two oceanographers. A significant reduction (12%) in the time required to complete the experimental program was achieved, as pointed out in Section 3. 2. 2.

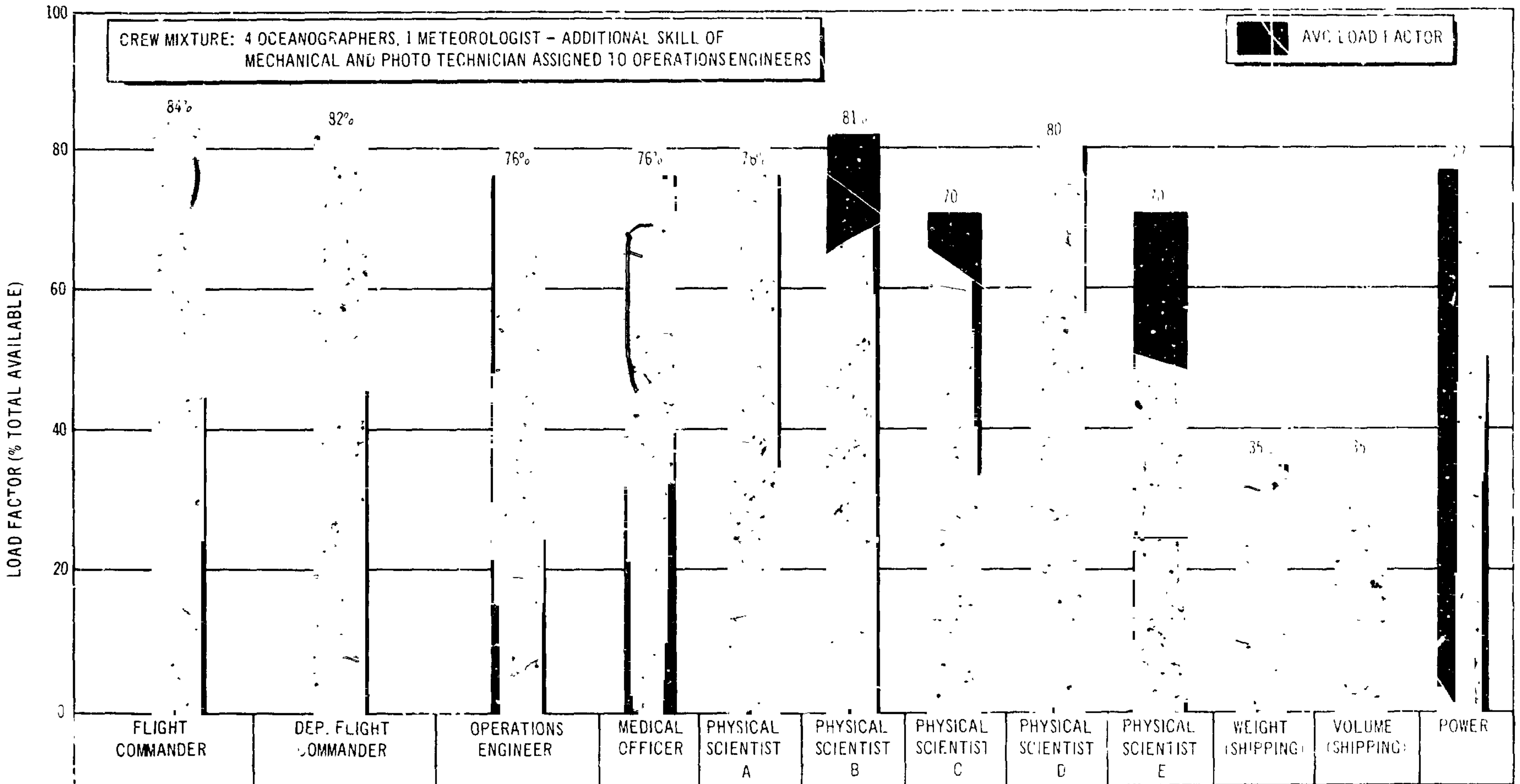
As the ratio of oceanographers to meteorologists is shifted still further, the relative utilizations of all the crewmen become better balanced (see Figure 3-14.)

The skills of the crew in this latter run were therefore more consistent with the needs of the Fisheries Production Program. The role of the meteorologist was simply overemphasized in the crew skill mix used for Run 2. The results of the SPEED scheduling philosophy easily pointed out this error and indicated the means of correcting it.

Figures 3-15 to 3-17 illustrate the effect of varying the number of oceanographers in the crew on the average utilization of specific skills rather than crewmen. As might be expected, the average number of nonutilized men with the skill of an oceanographer increases as the number of oceanographers in the crew increases. This, of course, indicates a decreasing shortage of oceanographers. Figures 3-15 to 3-17 also indicate the reason for the observed lack of variation in the utilization of crewmen without oceanography skills as the availability of this skill is increased. This reason is that the only cross-coupling between Physical Scientists A to E and other crew members is in the skills of observer and general worker, that is, these are the only skills oceanographers (physical scientists) share with other crewmen.

On the other hand, the average number of nonutilized men with the observer and general worker skills is very high (about 2. 1) and constant, regardless of the number of oceanographers on board, indicating a surplus rather than a shortage of these skills. Therefore, as more oceanographers are added, there is no reason to use them in the observer and the general worker mode. Instead, they are used almost exclusively as oceanographers.

It is interesting to note that this would necessarily change if the availability of observer and general worker skills is reduced in any way. One of these ways is, of course, a decrease in the crew size from nine to six men. Another way the availability of the above two skills would be reduced is to



FLIGHT COMMANDER	DEP. FLIGHT COMMANDER	OPERATIONS ENGINEER	MEDICAL OFFICER	PHYSICAL SCIENTIST A	PHYSICAL SCIENTIST B	PHYSICAL SCIENTIST C	PHYSICAL SCIENTIST D	PHYSICAL SCIENTIST E	
• MECHANICAL PHOTO TECHNICIAN • OBSERVER • GENERAL WORKER • EC/LS REPAIR SPECIALIST	• MECHANICAL PHOTO TECHNICIAN • MECHANICAL OPTICS ENGINEER • OBSERVER • GENERAL WORKER • RCS, SCS, STRUCTURE, REPAIR SPECIALIST	• ELECTRICAL AND MECH ENGINEER • OBSERVER • GENERAL WORKER • C & T. POWER REPAIR SPECIALIST • MECHANICAL PHOTO TECHNICIAN	• OBSERVER • GENERAL WORKER	• OCEANOGRAPHER • OBSERVER • GENERAL WORKER	• OCEANOGRAPHER • OBSERVER • GENERAL WORKER	• OCEANOGRAPHER • OBSERVER • GENERAL WORKER	• OCEANOGRAPHER • OBSERVER • GENERAL WORKER	• METEOROLOGY • OBSERVER • GENERAL WORKER	SKILLS POSSESSED BY CREWMEN

Figure 3-14. MORL Facility Load Factors (Experiments and Life-Support Operations) – (c)

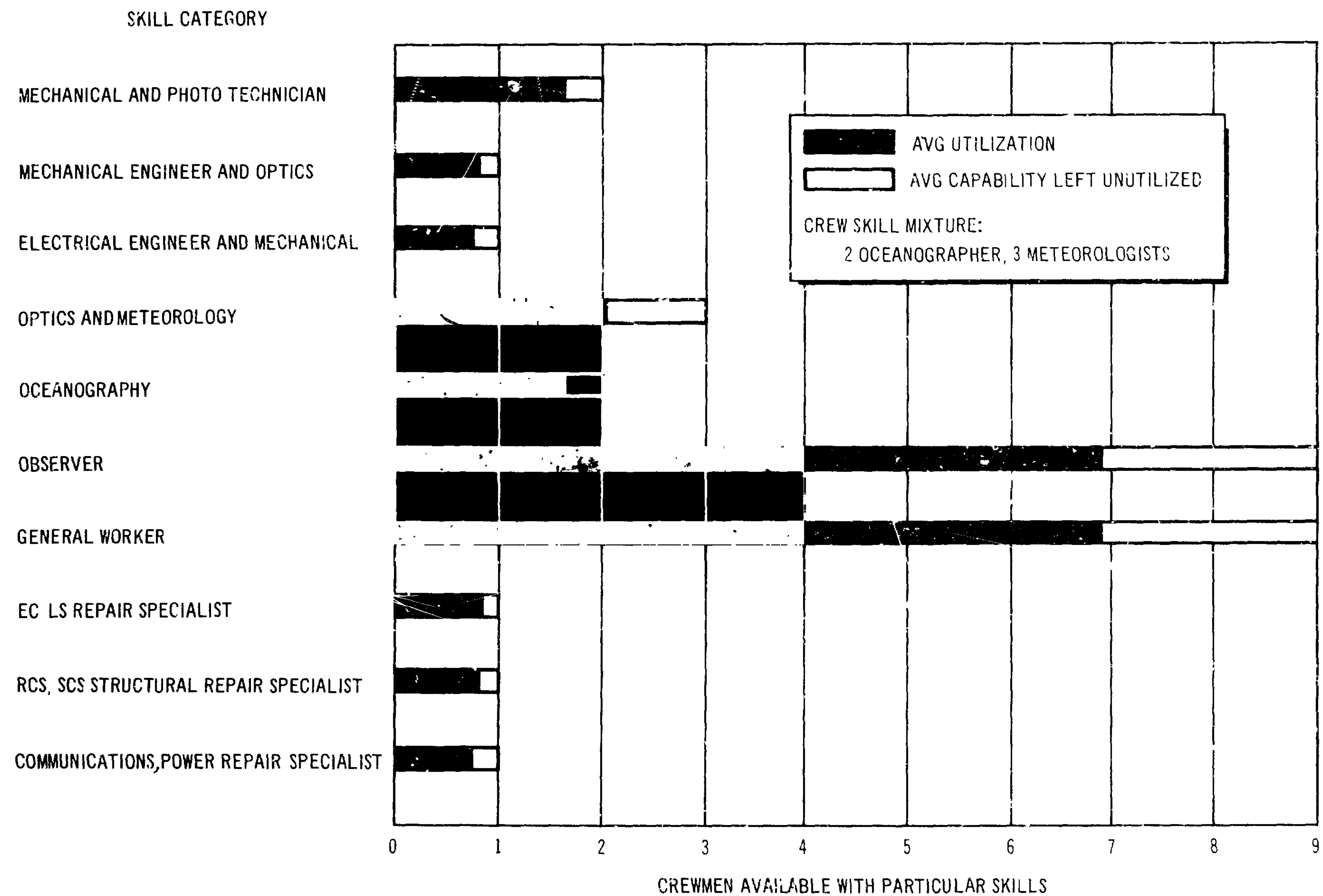


Figure 3-15. Utilization of Skills (9-Man Crew) – (a)

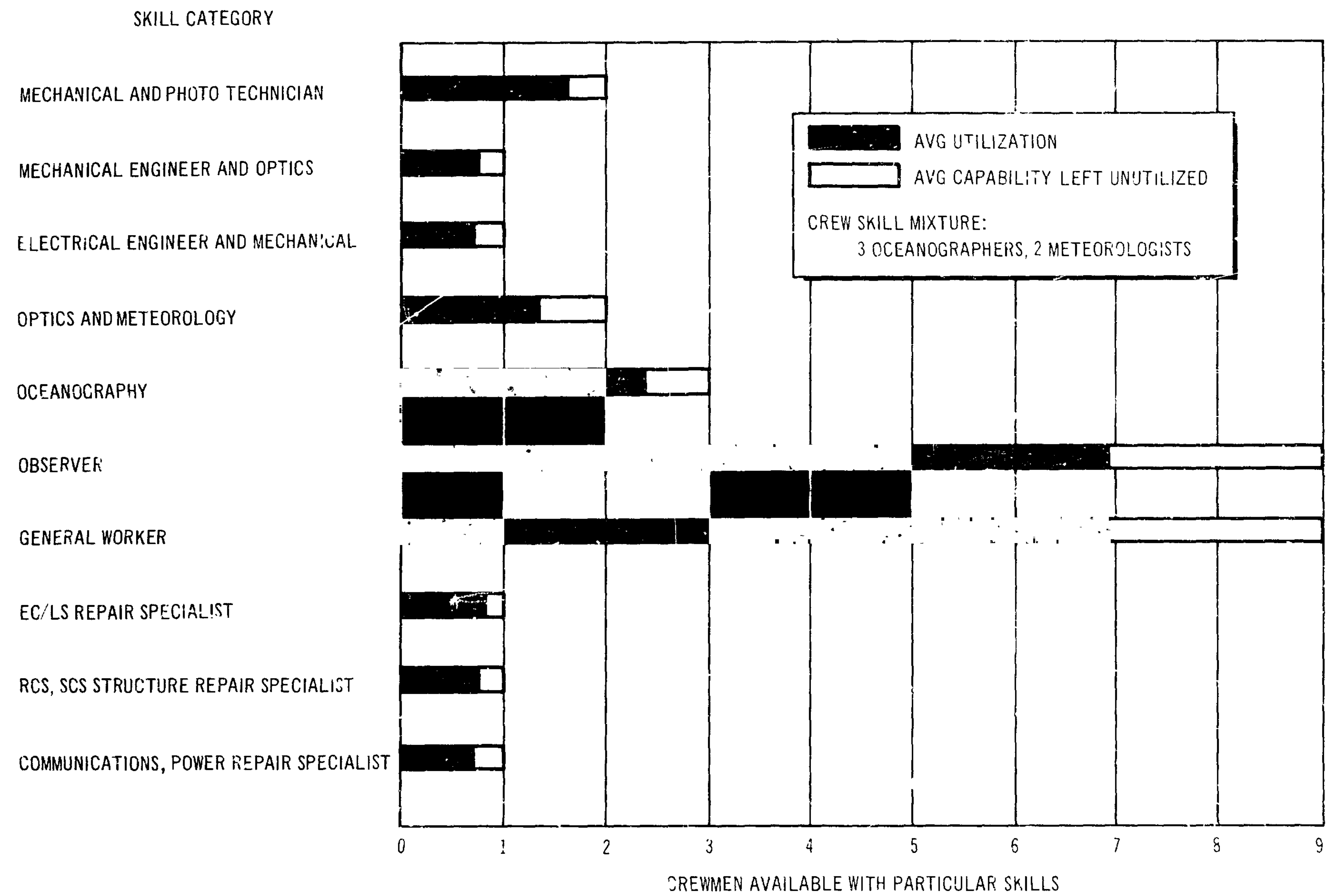


Figure 3-16. Utilization of Skills (9-Man Crew) – (b)

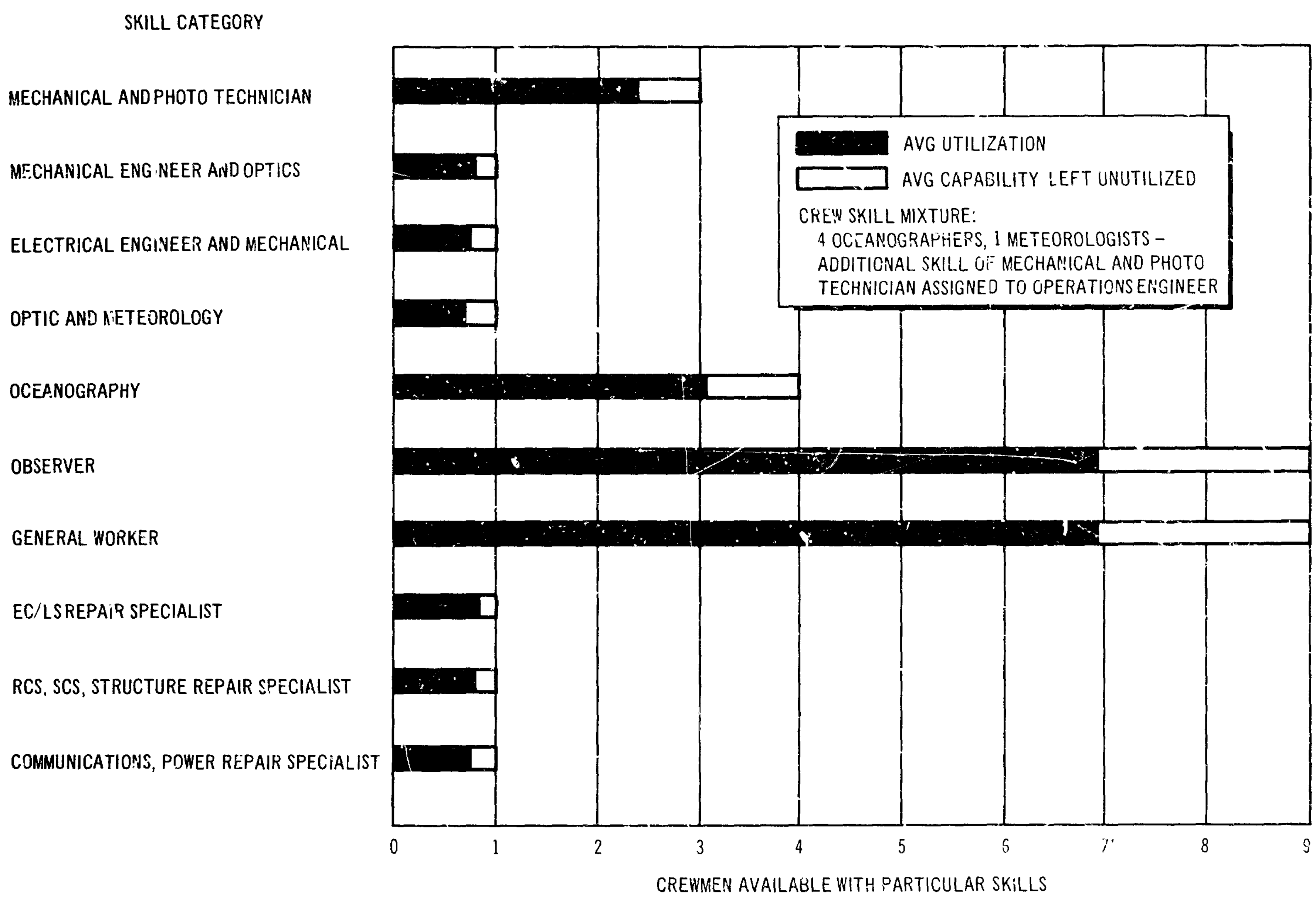


Figure 3-17. Utilization of Skills (9-Man Crew) – (c)

treat the nonscientific members of the crew as specialists devoted primarily to station operations and maintenance. For this somewhat unorthodox view, the nonscientific complement of the crew would not necessarily be assigned the skills of observer and general worker. As a consequence, jobs not requiring special training would be carried out by the scientist in the crew.

Figures 3-18 to 3-20 conclude the study of MORL resource utilization in an experimental program to assist Fisheries Production. These figures show monthly spikes of power utilization. It is to be noted that, although the average power utilization did not change with an increase in the number of oceanographers on board, the timing of the power peaks did. This is to be expected as a result of the increased availability of oceanographers, which allows the earlier start of some experiments.

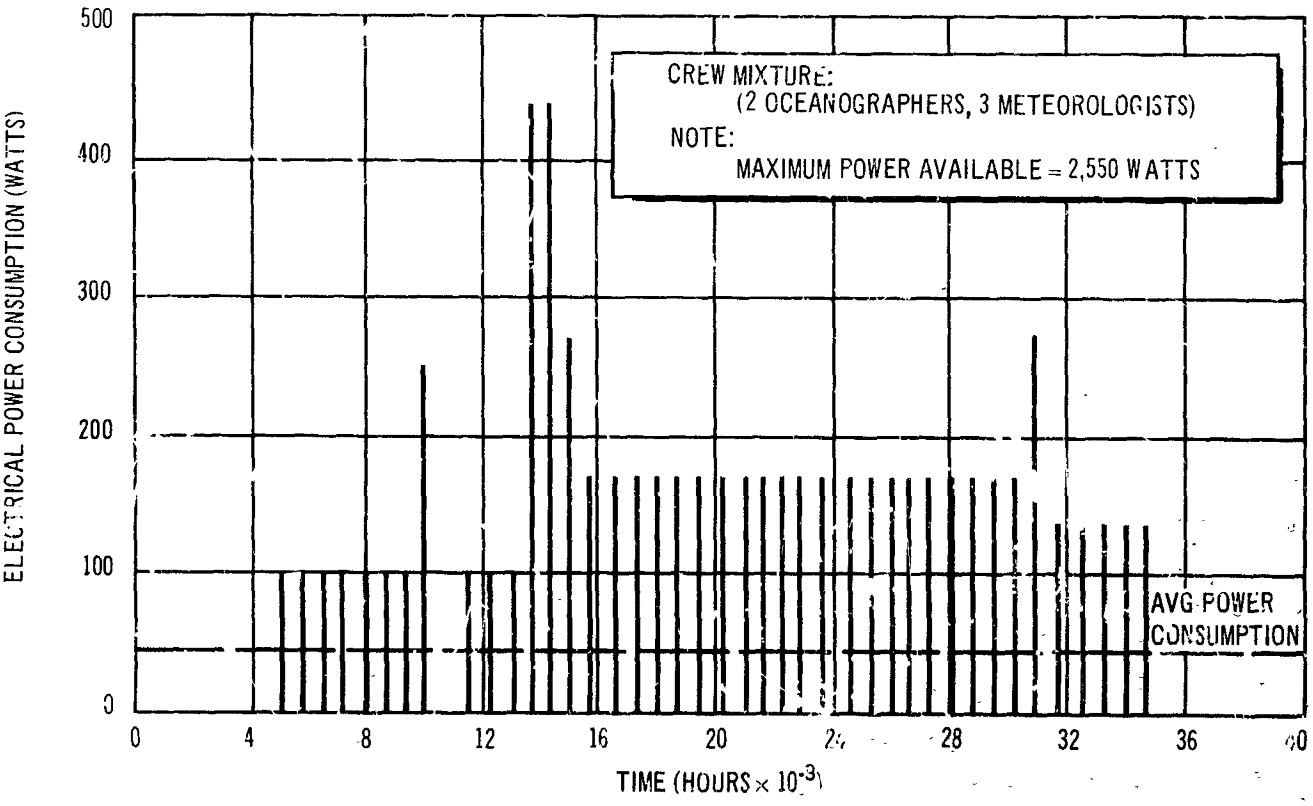


Figure 3-18. Electrical Power Consumption for Experiments – (a)

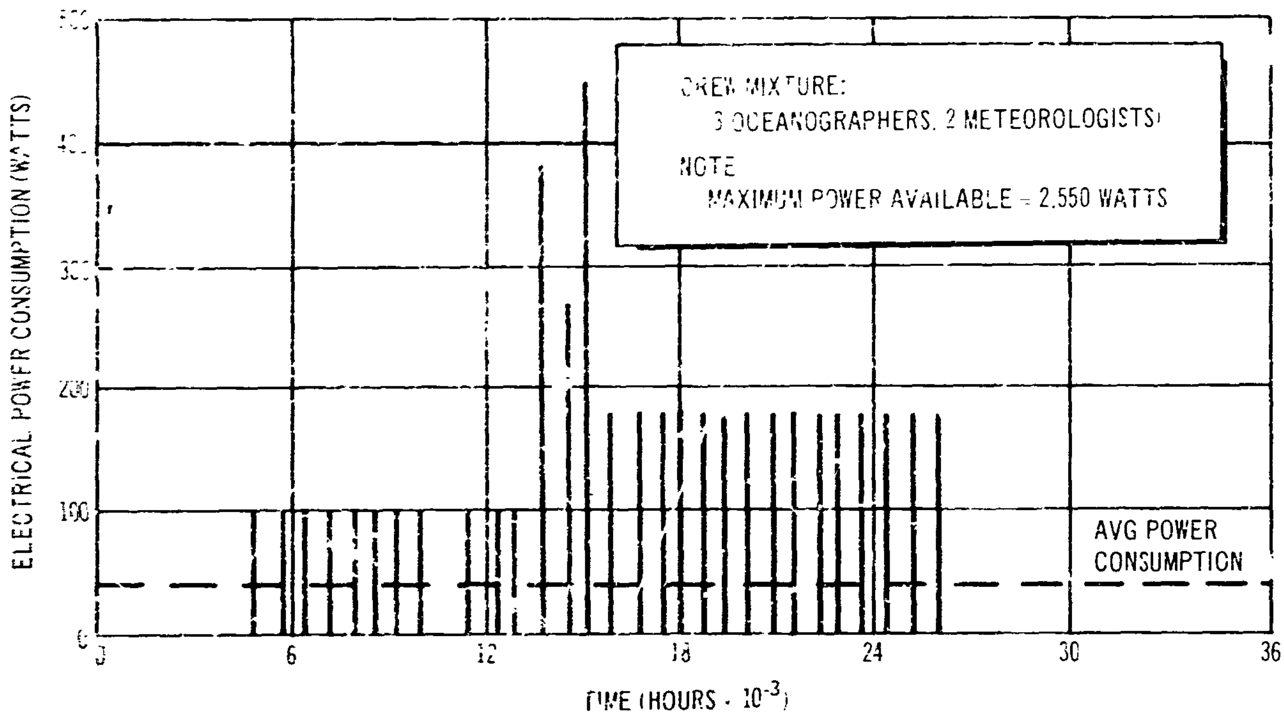


Figure 3-19. Electrical Power Consumption for Experiments – (b)

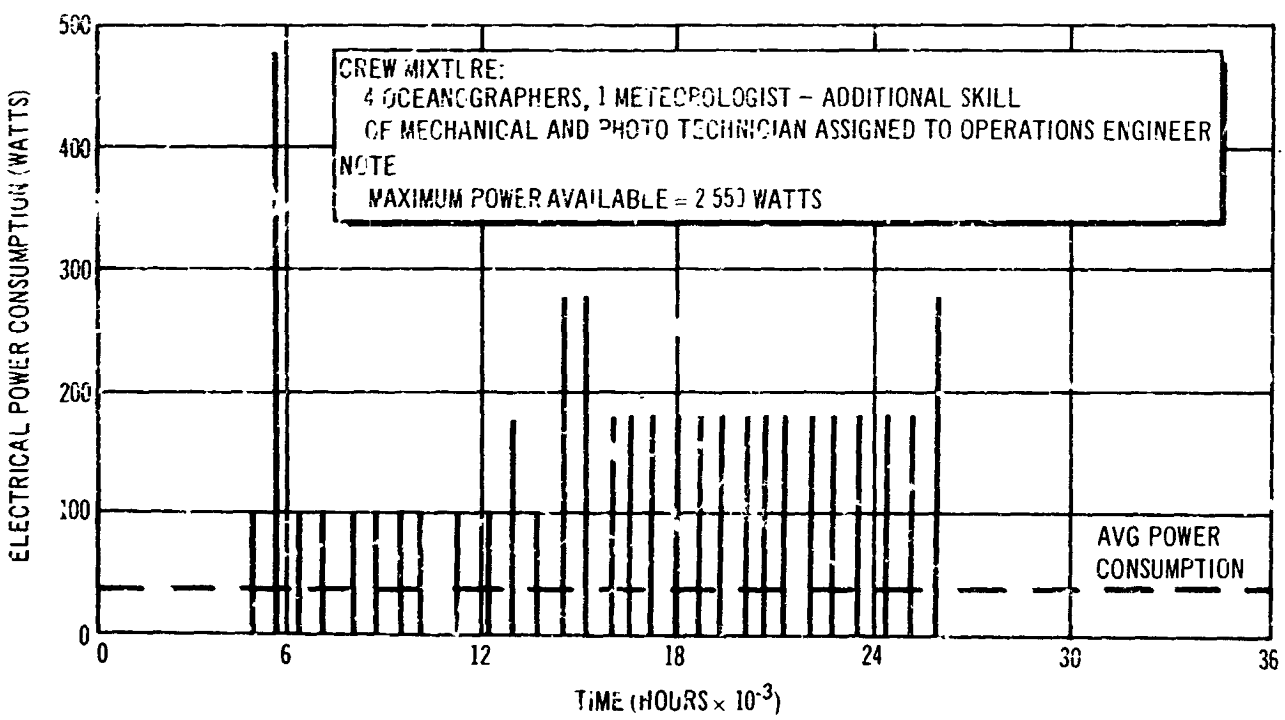


Figure 3-20. Electrical Power Consumption for Experiments – (c)

3.2.2 Program Duration

Table 3-4 shows the variation of program duration as a function of crew skill mixes.

Table 3-4

EFFECT OF VARYING CREW SKILL MIXES ON PROGRAM DURATION

Run	Crew: Oceanographers	Crew: Meteorologists	Program Duration (hours)
1	2	3	40, 290
2	3	2	35, 314
3	4	1	34, 702

As indicated, the increase from two to three oceanographers resulted in speeding up the completion of the 66 experiments by nearly half a year. An increase from three to four oceanographers did not result in significant reductions in program duration.

Perhaps an even more significant measure of the improvements achieved is a comparison of actual program duration to ideal program duration. Ideal program duration may be defined as the time required to complete all 66 experiments, provided that the experimental program is constrained only by the PERT-type logical network of Figure 3-11, that is, if it is performed in an orbital laboratory with infinitely large resources.

The ideal program duration was calculated for the three major subobjectives necessary to render operational assistance to Fisheries Production. These subobjectives are the ability to predict plankton concentration, plant concentration, and fish stock distribution.

As shown in Figure 3-21, actual program duration is only about one third more than the ideal program duration. In a sense, therefore, the MORL can be considered to be about 75% as efficient in completing the 66 experiments as an infinitely large orbiting research laboratory.

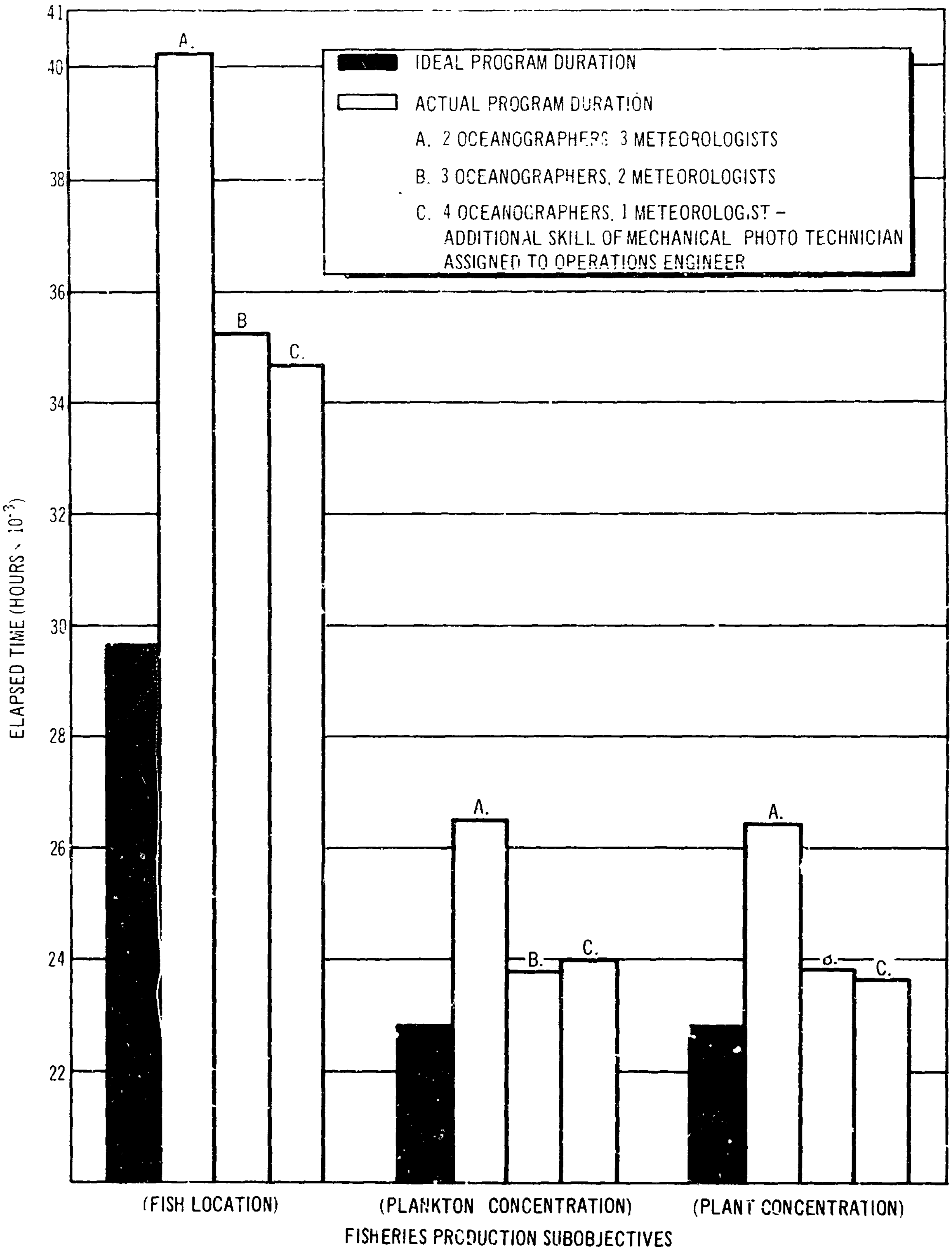


Figure 3-21. Comparison of Elapsed Times

3.2.3 Assessment of MORL/Experiment Interface Limitations

For the figure of merit of experiment-hours of delay developed in Section 3.1.6, the relative contribution of various MORL resources to delays in completing the 66 experiments was studied. The results of this study are summarized in Figures 3-22 to 3-24. As indicated above, the shortage of oceanographers is the predominant cause of the delays.

As the skills of meteorologist were transferred to those of oceanographer progressively in Runs a to c (Figures 3-22 through 3-24) the hours of delay in the performance of experiments, attributed to an unavailability of oceanographers, are significantly reduced. The delays caused by the absence of a meteorologist are not greatly increased even when the number of crewmen with that skill is reduced to one. The skill mix used in Figure 3-24 is seen to be most compatible with the requirements of the Fisheries Production Program. Thus, as previously mentioned, the crew skill mix is very sensitive in its effects upon program duration and experiment-hours of delay.

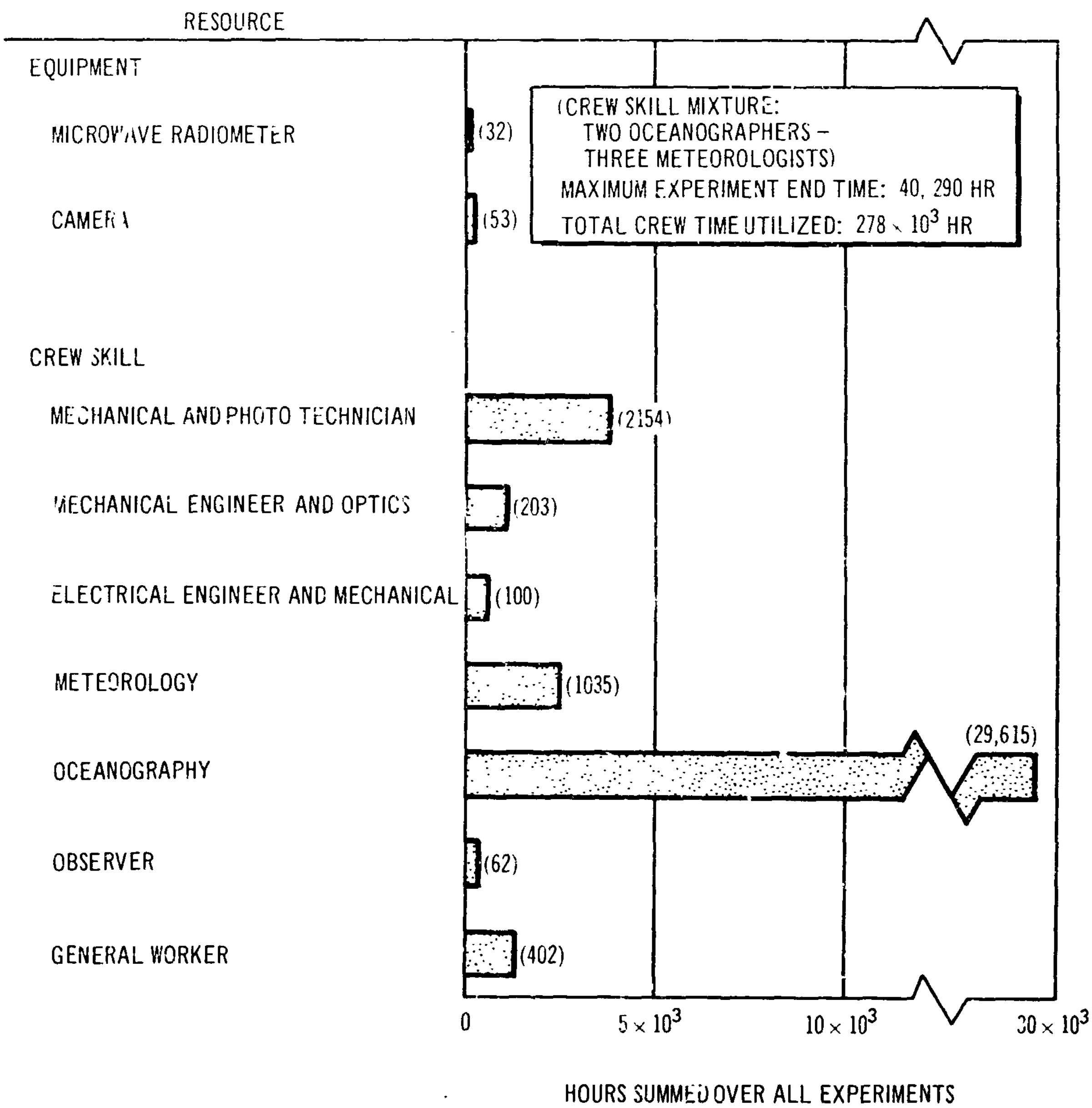


Figure 3-22. Relative Contribution of Resource Deficiencies to Experiment Delays – (a)

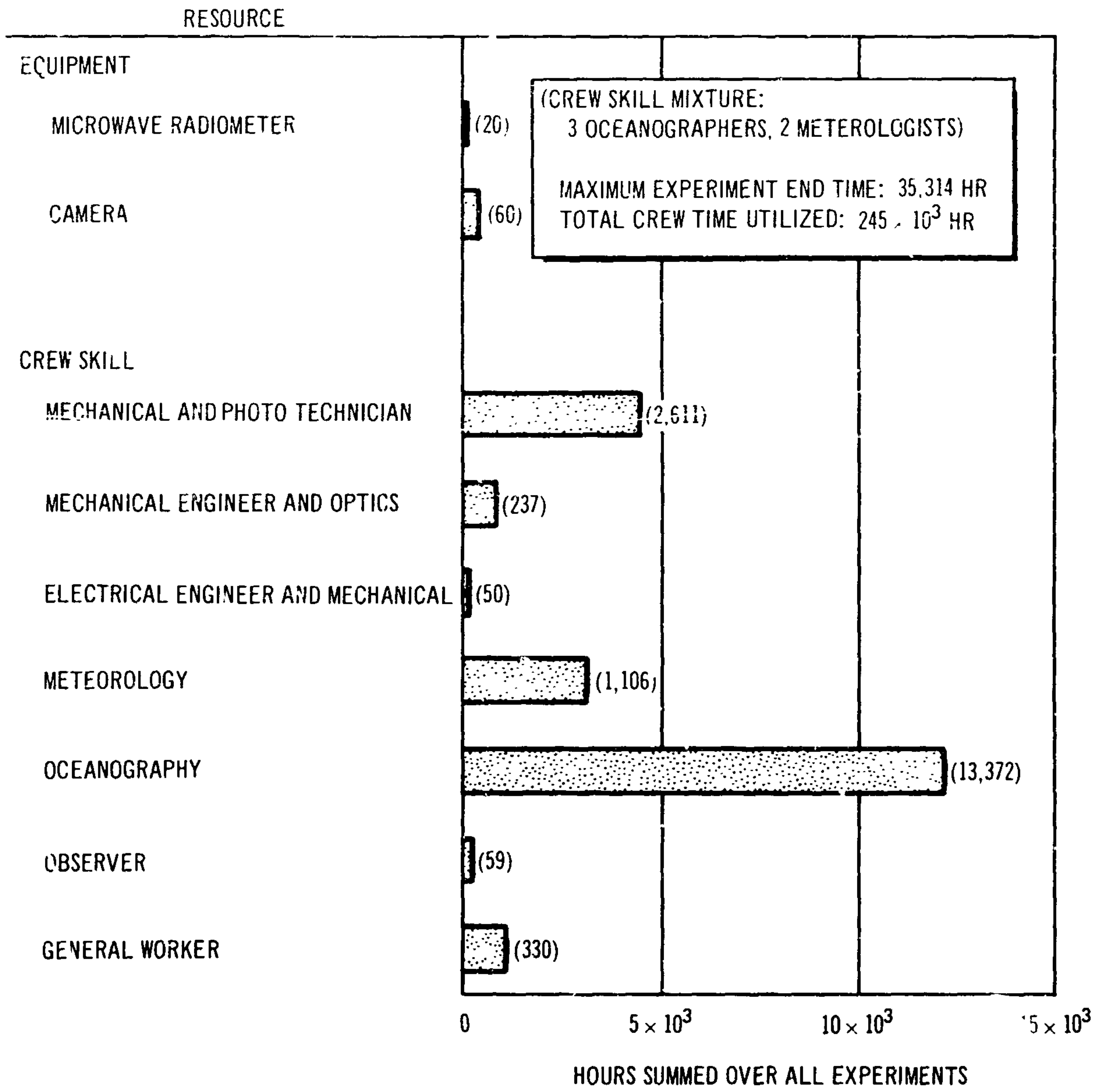


Figure 3-23. Relative Contribution of Resource Deficiencies to Experiment Delays – (b)

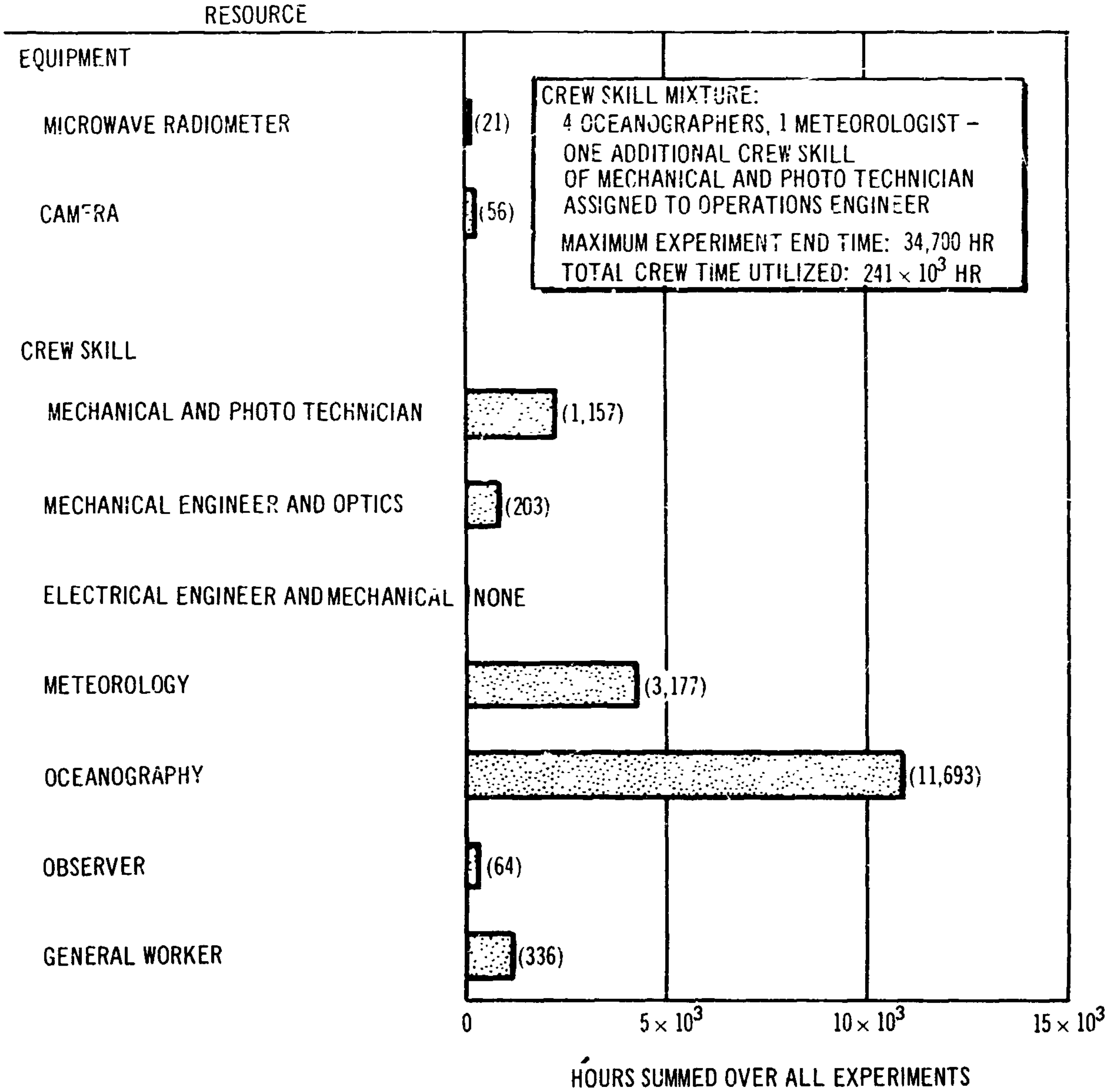


Figure 3-24. Relative Contribution of Resource Deficiencies to Experiment Delays – (c)

Section 4
SUBSYSTEM ACCOMMODATION OF MISSION REQUIREMENTS

4.1 INTRODUCTION

The purpose of the analyses presented in this section is to determine the degree to which the baseline MORL system can accommodate those mission requirements developed in Task II. The baseline MORL is defined in this report as that design current at the end of the Phase IIa study. The mission requirements consist of satisfactorily operating in a 200-nmi altitude, 53° inclination orbit; a 200-nmi altitude, 90° inclination orbit; and a 19,350-nmi, 28.3° inclination orbit.

4.1.1 50° Inclination Mission

The subsystem modifications that must be made to the baseline MORL in order to accommodate the low altitude missions are shown in Table 4-1. The 50° inclination mission requirements can be met by adding 165 lb of radiation shield material to the top dome of the laboratory. This could be done by increasing the effective aluminum thickness by 0.02 in., thus providing adequate shielding for an exposure of 1 year, including the dose received from two major solar flare events.

4.1.2 Polar Mission

To accommodate the polar mission, three changes must be made to the baseline MORL system as shown in Table 4-1: 1) The increased radiation environment at this inclination requires an additional 1,820 lb of shielding material. This is necessary to attenuate the dose received from a major solar flare event to a value below the single dose allowed to the lens of the eye and the crewmen's skin. The solar flare proton radiation is higher at this inclination than at 53° because the shielding effect of the electromagnetic field around the earth is minimal at 90° inclination. The 1,820 lb of shielding

Table 4-1

SUBSYSTEM CHANGES REQUIRED FOR MISSION ACCOMMODATION

Subsystem	Change		
	50° Inclination 200 nmi Mission	90° Inclination 200 nmi Mission	Synchronous Mission
EC/LS	None	None	Radiator area must be reduced by removing 13 circumferential tubes.
Power	None	None	None
SCS	None	None	None
Communications	None	Include the Guaymas station for adequate coverage	Add S-band capability
Configuration and Structures	Add 165 lb of radiation shielding	Add 1,820 lb of radiation shielding	Excessive radiation shielding required >20 tons
Logistics	None	Saturn V required	Saturn V required

could be provided by adding 0.21, 0.39, and 0.06 in. of polyethylene to the laboratory bottom, cylindrical sides, and dome top respectively. 2) In order to meet the navigation accuracy requirements at least one tracking opportunity per orbit for three successive orbits, followed by a command opportunity on the succeeding orbit is necessary. The two baseline ground tracking sites at Cape Kennedy and Corpus Christi cannot provide this capability for the polar mission. A third ground tracking network, probably at Guaymas, must be added which would not only satisfy the once per orbit tracking for three successive orbit criteria but would also provide an addition 25% (7 min.) in the average daily contact time. 3) The payload loss incurred by launching from Cape Kennedy with the attendant range safety restrictions reduces the payload capability of the Saturn IB and makes a Saturn V launch vehicle necessary for this mission.

4.1.3 Synchronous Mission

Further analysis is required before the baseline MORL could be specified for use on a synchronous mission. The radiation shield weight required for this mission is higher than previously reported. Variation in weight due to uncertainties in the electron flux level at this altitude, is from 4,400 to 110,000 lb. The increase is caused by improvements in the calculation techniques used here over those used in Phase IIa. These changes are discussed in detail in Section 6 of this report. The larger weight requirement may surpass the amount that could be considered on a Saturn V launch (about 30,000 lb) and the thick material may cause installation and interference problems that must be ascertained. Several areas of study are recommended to alleviate this problem and are also discussed in Section 6.

In addition to the foregoing conclusions concerning radiation shielding, three other portions of the MORL system must be modified in order to accommodate the synchronous mission:

1. The EC/LS radiator size must be reduced to account for the reduced heat influx encountered at this altitude. This modification could be easily accomplished by removing 13 of the 41 circumferential radiator tubes. Failure to remove these tubes would result in very cold fluid temperatures in the radiator tubes; this would increase the pumping power required to an excessive value.

2. The communications system must account for a 25-dB additional space loss of the transmission signal magnitude at this great distance. To provide the required transmission bandwidth of this mission, an S-band system must be added to the MORL baseline. This S-band system would be similar to the Apollo unified S-band system.

3. The Saturn V launch vehicle is required to, and can, place the MORL into a synchronous mission without radiation protection. However, the large radiation shield weight required surpasses the Saturn V capability, and other radiation shield measures as mentioned must be taken.

Table 4-1 indicates that, except for the prohibitive radiation shield requirements for the synchronous mission, MORL subsystem modifications necessary to accommodate the three specified missions are relatively minor. This conclusion was not unexpected because of the original design requirements imposed upon MORL. To meet the requirements of each portion of the original mission a high degree of inherent flexibility was essential. Consequently, when new mission requirements were imposed on the bascline design, as defined in Phase IIa, it was found that the large majority of these capabilities were already present; and the remainder could be achieved by minor modifications to existing designs.

4.2 MISSION DESCRIPTION

Mission requirements are discussed in Section 2 of this report. In order to satisfy these requirements and determine the adequacy of MORL to respond to more ambitious requirements, three Earth orbits were investigated. These included 50° and 90° inclination orbits in the low altitude range (200 nmi) and a synchronous orbit at 19,350 nmi altitude and 28.3° inclination. The methods and vehicle chosen to achieve these orbits were identical to those discussed in Reference 3 and are summarized in the following paragraphs:

1. The Saturn IB is adequate to place the MORL or its logistics vehicle into a 200 nmi altitude, 50° inclination orbit.
2. The Saturn V will be used to place the MORL or its logistics vehicle into a 200 nmi altitude polar orbit. The orbit plane rotation technique is recommended since it will result in adequate payload without infringing on range safety boundaries. The southern launch method is recommended for future study, however, because of the high payload capability.
3. The Saturn V will place the MORL or its logistics vehicle into the 24-hour synchronous orbit at 28.3° inclination dependent upon a solution to the radiation shield problem.

A summary of the sequence of events for the MORL and logistics vehicle launches are shown in Tables 4-2 and 4-3, respectively.

4.2.1 50° Inclination Orbit

4.2.1.1 Laboratory Launch

The laboratory will be launched unmanned by a Saturn IB launch vehicle from the Eastern Test Range at an inertial azimuth of 44.5° from true North. Figure 4-1 shows the instantaneous impact point (IIP) trace of a Saturn IB vehicle launched at this azimuth and flown without doglegging. A Saturn V will cover the same general path; however, the time history and staging points will vary slightly. The Saturn IB IIP will cross an inhabited land mass (France) approximately 10 sec prior to orbital injection. (The total time to cross the European land mass will be between 3 and 4 sec of burning.) Therefore, State Department waivers will be required before this trajectory

Table 4-2

EVENT SEQUENCING

UNMANNED LABORATORY LAUNCH

Baseline Mission (i = 50° h = 200 nmi Saturn IB)	Polar Mission (i = 90° h = 200 nmi Saturn V)	Synchronous Mission i = 28.3° h = 19,350 nmi Saturn V)
Boost phase at azimuth = 44.5°	Boost phase at azimuth = 44.5°	Boost phase at azimuth = 90°
Inject into elliptic orbit perigee = 100 nmi;apogee = 200 nmi (nominal)	After 95 sec burn on S-IVB inject into 100 nmi circular orbit	After 129 sec burn on S-IVB inject into 100 nmi circular orbit
Separate S-IVB	4.75-hours coast in circular orbit	Coast time will be a function of final position desired.
45-min. coast	Restart S-IVB and rotate orbit plane 40° and inject into elliptic orbit perigee = 100 nmi, apogee = 200 nmi (nominal)	Restart S-IVB and inject into elliptic orbit. (perigee 100 nmi, apogee 19,350 nmi, 245 sec burn time on S-IVB)
Circularize with laboratory propulsion system at nominal altitude of 200 nmi	Separate S-IVB	5.25-hour coast
	45-min. coast	Restart S-IVB and circularize orbit at 19,350 nmi (88 sec burn time)
	Circularize with laboratory propulsion at nominal altitude of 200 nmi	

Table 4-3

EVENT SEQUENCING
MANNED RENDEZVOUS VEHICLE

Baseline Mission $i = 50^\circ$ $h = 200$ nmi	Polar Mission $i = 90^\circ$ $h = 200$ nmi	Synchronous Mission $i = 28.3^\circ$ $h = 19,350$ nmi
Apollo - Saturn IB	Apollo - Saturn V	Apollo - Saturn V
Boost into elliptic orbit: perigee = 87 nmi, apogee = 200 nmi, azimuth is function of launch time. S-IVB is separated	Boost into 100 nmi circular orbit. Azimuth = 44.5°	Boost into 100 nmi circular orbit. Azimuth 90°
Plane rotation, apogee, and perigee adjustment impulses made on ground command. Duration of maneuver variable (up to 2.75 days)	4.75-hour coast followed by S-IVB ignition to perform plane rotation and elliptic injection. Separate S-IVB. Note: These steps are made to parallel the laboratory launch as closely as possible	Coast in parking orbit followed by injection into elliptic transfer orbit. (perigee 100 nmi apogee 19,350 nmi) Note: These maneuvers are made to parallel the laboratory launch as closely as possible
Radar acquisition and closed loop impulses. Duration 70 min.	Plane rotation, apogee, and perigee adjustment impulses made on ground command. Duration variable (up to 3.1 days)	Injection into catchup elliptic orbit after coast to apogee based on ground commands
		Plane rotation, apogee, and perigee adjustment impulses based on ground command. Duration approximately 1 day
Braking and docking maneuver. Duration 15 to 30 min.	Closed loop maneuvers Duration 70 min.	Braking and docking maneuver. Duration 15 to 30 min. Closed loop phase is eliminated, and functions are performed by ground tracking.
All impulses made by rendezvous propulsion after S-IVB separation	Braking and docking maneuver. Duration 15 to 30 min.	
	Rendezvous propulsion used after S-IVB separation	

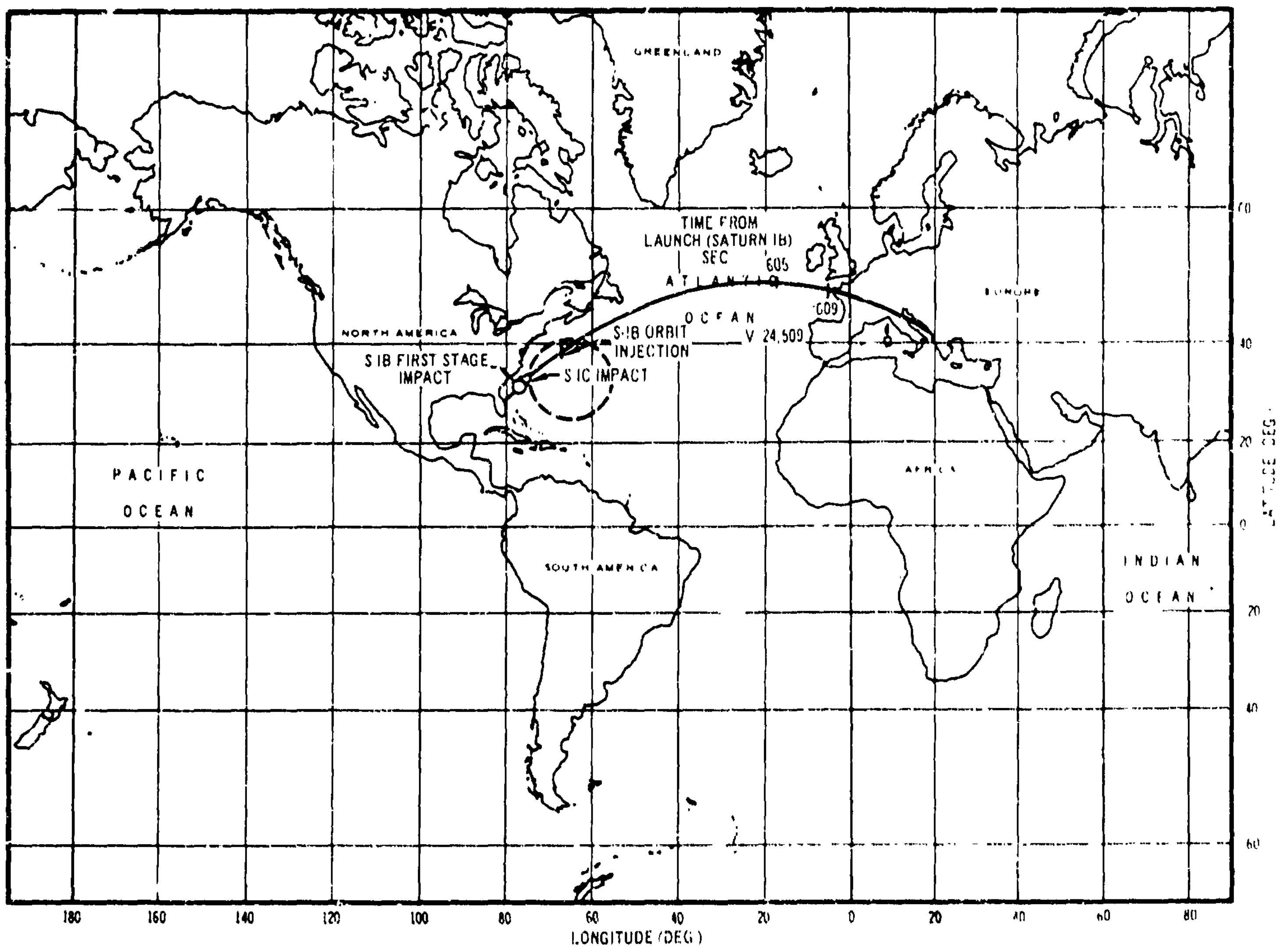


Figure 4-1. Saturn Launch Trajectory – 50° Mission

can actually be flown. The Saturn V will experience the same difficulties in obtaining range approval. It should be pointed out that the highly reliable Delta vehicle has previously obtained range and State Department approval to make similar flights.

The first stage impact points for the Saturn IB and Saturn V launch vehicles are in the broad ocean area. Tracking from Bermuda will yield complete coverage of the injection point. Therefore, aside from the range safety waivers, this trajectory presents no problem in achieving the required 50° inclination.

Because it possesses sufficient payload capability, the Saturn IB is the recommended laboratory launch vehicle. It must be used in the elliptic injection mode to place the laboratory and a minimum amount of consumables into a 200 nmi orbit. A laboratory propellant expenditure of 650 lb (lab I_{sp} = 285 sec) is required for the apogee injection impulse. The launch profile will be as follows:

1. The Saturn IB will rise vertically for 25 sec during which time the vehicle will be rolled to an inertial azimuth of 44.5° measured from true north.
2. After 25 sec, a pitch rate will be commanded for 10 sec following which the vehicle will attempt to fly a zero angle of attack, gravity turn trajectory.
3. At S-IVB burnout (approximately 620 sec from liftoff), the payload will be at perigee (100 nmi) of an elliptic orbit having an apogee of 200 nmi. (Note: The perigee altitude of the laboratory has not been optimized for this study.) The expended S-IVB is separated and retrofired away from the payload; the payload will then coast to apogee.
4. After approximately 43 min. of coast, the laboratory reaction control system is ignited and fires for 5.15 min. to circularize the orbit at 200 nmi.

4.2.1.2 Rendezvous Profile

Although still utilizing the Gemini parallel plane technique, rendezvous philosophy will be modified from that determined for the low inclination orbit because of the significantly larger out-of-plane angles encountered. The restriction of rendezvous within 24 hours after launch will be waived to keep the rendezvous propellant requirements within reasonable bounds. Figure 4-2 shows the out-of-plane angle and the corresponding instantaneous launch azimuth required as a function of launch time for the parallel plane launch technique. Earth oblateness effects were not considered during the study for two reasons: (1) the short duration of the study did not permit the inclusion of second order effects, and(2) launch azimuth biasing techniques discussed in Reference 3 can be applied to eliminate this problem.

The launch azimuth boundaries assumed for ETR are 40° and 108° measured from true North. From Figure 4-2 it is obvious that range safety considerations preclude a split launch window, therefore, all rendezvous launches will utilize northerly azimuths. In addition, to obtain an appreciable launch window, large out-of-plane corrections are required. It is recommended that the rendezvous launch window be restricted to that minimum time commensurate with launch pad capabilities.

Figure 4-3 illustrates the large payload penalties associated with long-duration launch windows. It shows the fraction of vehicle payload required as propellant to accomplish the rendezvous maneuvers as a function of launch window. The zero launch window represents a coplanar situation, the only rendezvous maneuvers requiring propellant expenditure are orbit circularization, braking, and docking. The launch profile consists of a parallel plane launch into an elliptic orbit with perigee at 87 nmi and apogee at 200 nmi, followed by circularization and rotation of the orbit and, finally, docking with the laboratory. These sequences are more thoroughly described in Reference 4. After the initial injection into orbit, all impulses will be provided by the rendezvous propulsion system. The following is a breakdown of the velocity components required:

Requirement	Velocity (fps)
Impulsive orbit circularization	194
Mechanization error pad	240
Docking impulse	50
Impulsive plane rotation	f (Launch window)
Error pad for plane rotation	K [f(Launch window)] *

*In Figure 4-3, K factors of 0.1 and 0.01 are shown.

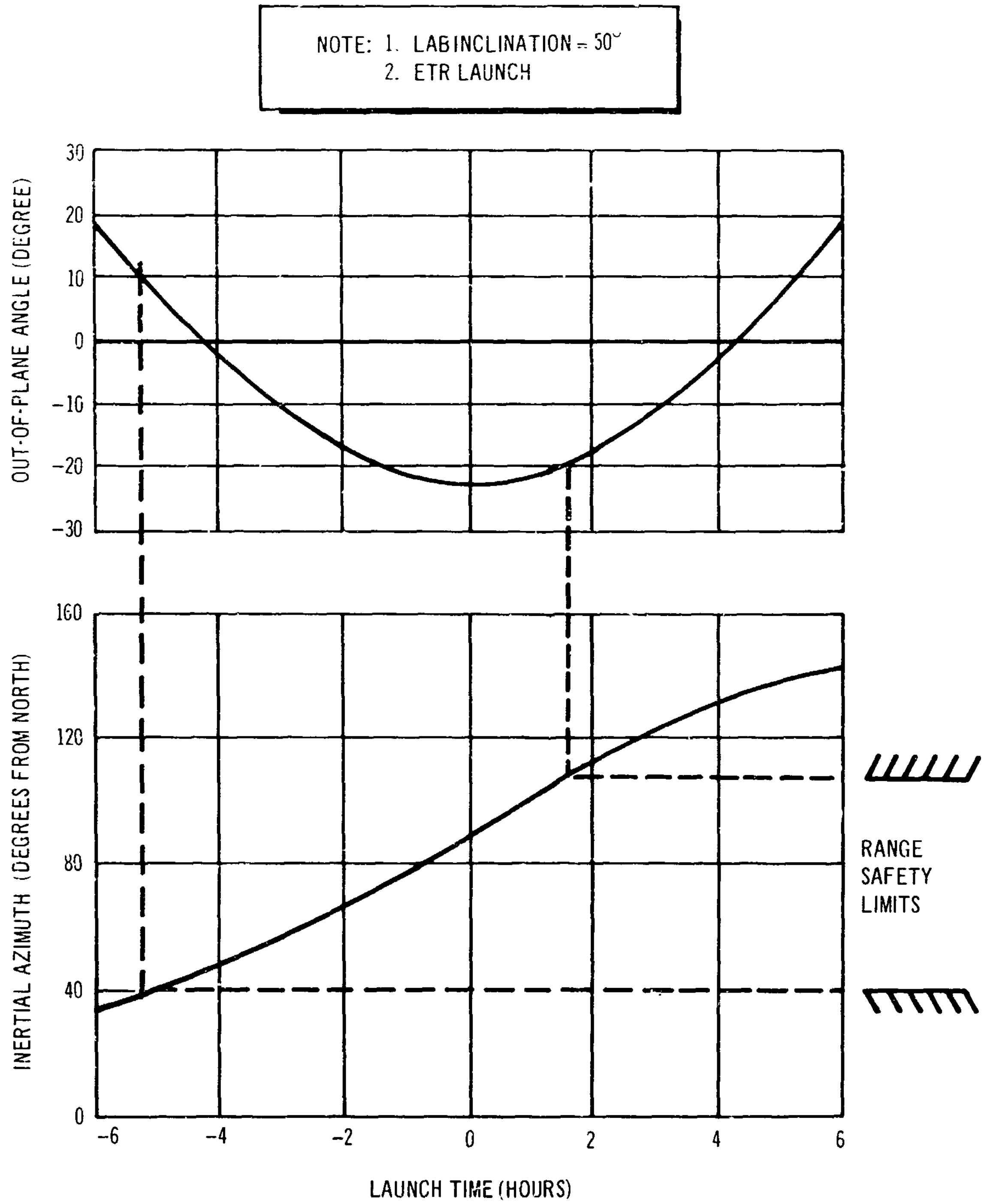


Figure 4-2. Variation of Out-of-Plane Angle and Inertial Azimuth with Launch Time

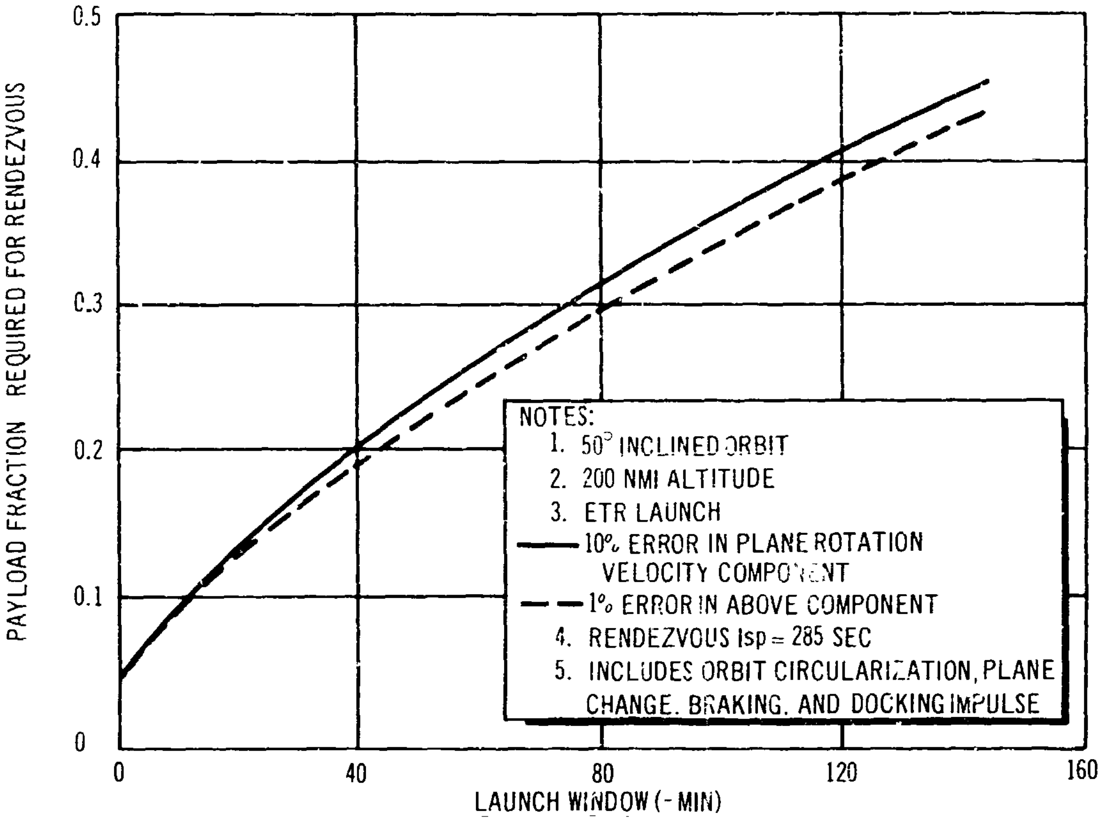


Figure 4-3. Rendezvous Payload Loss as a Function of Launch Window

The summation of these components represents an estimate of the overall rendezvous system impulse requirement. Figure 4-3 represents this impulse in terms of payload fraction.

Figure 4-3 shows that a 10-min. launch window requires about 10% of the Saturn launch vehicle payload in the initial elliptic orbit be in the form of rendezvous propellant. To achieve the 2-hour launch window available in the low inclination orbit, approximately 40% of the payload must be in the form of rendezvous propellant. From these arguments, it is apparent that the determining factor in arriving at a design launch window is to achieve a sufficiently high probability of having a launch rather than providing for a minimum time to rendezvous. This is the major deviation in rendezvous philosophy from the low inclination mission. It is no longer possible to guarantee a rendezvous within 24 hours after launch. From Figure 4-4 the synodic period of a 200-nmi circular orbit and an 87/200 nmi elliptic orbit can be determined as 2.5 days. Further, because some adjustments in the catch-up orbit must be made before a full 360° of relative orbital travel, the rendezvous vehicle will have to sustain itself in its various catch-up orbits for about 2.75 days.

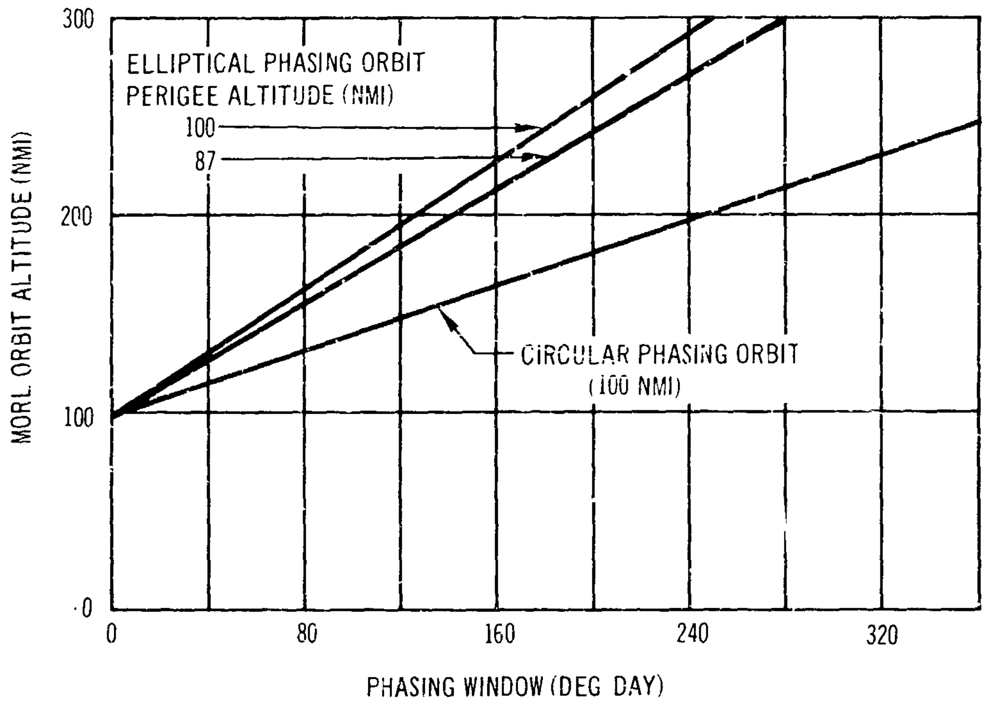


Figure 4-4. Resupply Phasing Window

It should be noted that orbital regression resulting from Earth oblateness affects the time of target plane passage through the launch site, causing it to occur slightly earlier each day. The period of this motion is 59 days, resulting in rendezvous launch opportunities occurring for approximately 29 days in daylight followed by equal period of night-time passages. (Day-night refers to two equal 12-hour periods without regard to seasonal variations.)

4.2.1.3 Abort Considerations

As stated earlier, the rendezvous launches must be along the northerly azimuths because of range safety restrictions. This naturally means that impact points will be possible in the North Atlantic in the event of an abort during the boost phase. This is a very severe environment, particularly during the winter months, and detailed operational plans have been established to permit rapid, reliable recovery of downed crewmen. Operational plans are discussed in Reference 2.

Figure 4-1 shows that the vehicle IIP crosses the European continent. The rendezvous propulsion system can generate more than enough impulse to inject the Apollo into a low altitude orbit that will permit recovery at some preselected site under controlled conditions and preclude inadvertant impacts on land.

4.2.2 Polar Orbit

4.2.2.1 Launch

Several Saturn boost profiles were investigated in an attempt to achieve a polar orbit with a Cape Kennedy launch. These methods were as follows:

1. A two-dimensional, no dogleg, launch trajectory, that is, launching the vehicle at the proper azimuth to achieve polar orbit at burnout.
2. A launch at 44.5° azimuth and commencing a northerly dogleg at second stage ignition.
3. A launch at 44.5° azimuth and beginning the northerly dogleg when the vehicle inertial velocity reached 18,000 fps.
4. Launching into a low altitude orbit at 50° inclination (launch azimuth = 44.5°) and rotating the orbit plane at some subsequent nodal crossing.
5. Launch at an azimuth of 146° and dogleg to the West after second stage ignition, and then an easterly dogleg to bring the vehicle into polar inclination.

Figure 4-5 shows the percent of payload remaining as a function of orbit inclination for the five techniques described above. It is immediately obvious that method No. 3 cannot place any payload into a polar orbit and must be eliminated from further consideration.

Utilizing the two-dimensional launch trajectory described in method No. 1, the vehicle must be launched at an azimuth of 18[illegible]° or 358°, measured from true north. In either case, the launch vehicle will overfly populated areas shortly after liftoff, an unacceptable violation of range safety regulations. This condition can be alleviated by shifting the launch site to WRT, where the 182° azimuth flight path is over water. Barring this contingency, method No. 1 is unacceptable.

In method No. 2, IIP trace of a vehicle launched at a 44.5° azimuth and beginning the dogleg maneuver to the north at second stage ignition is over densely populated areas in the United States and Canada during a large portion of the powered flight phase. As shown by Figure 4-6, the orbit inclination achieved by the trace was only 73.5°, but the range safety problems appeared so prohibitive that this technique was dropped from further consideration.

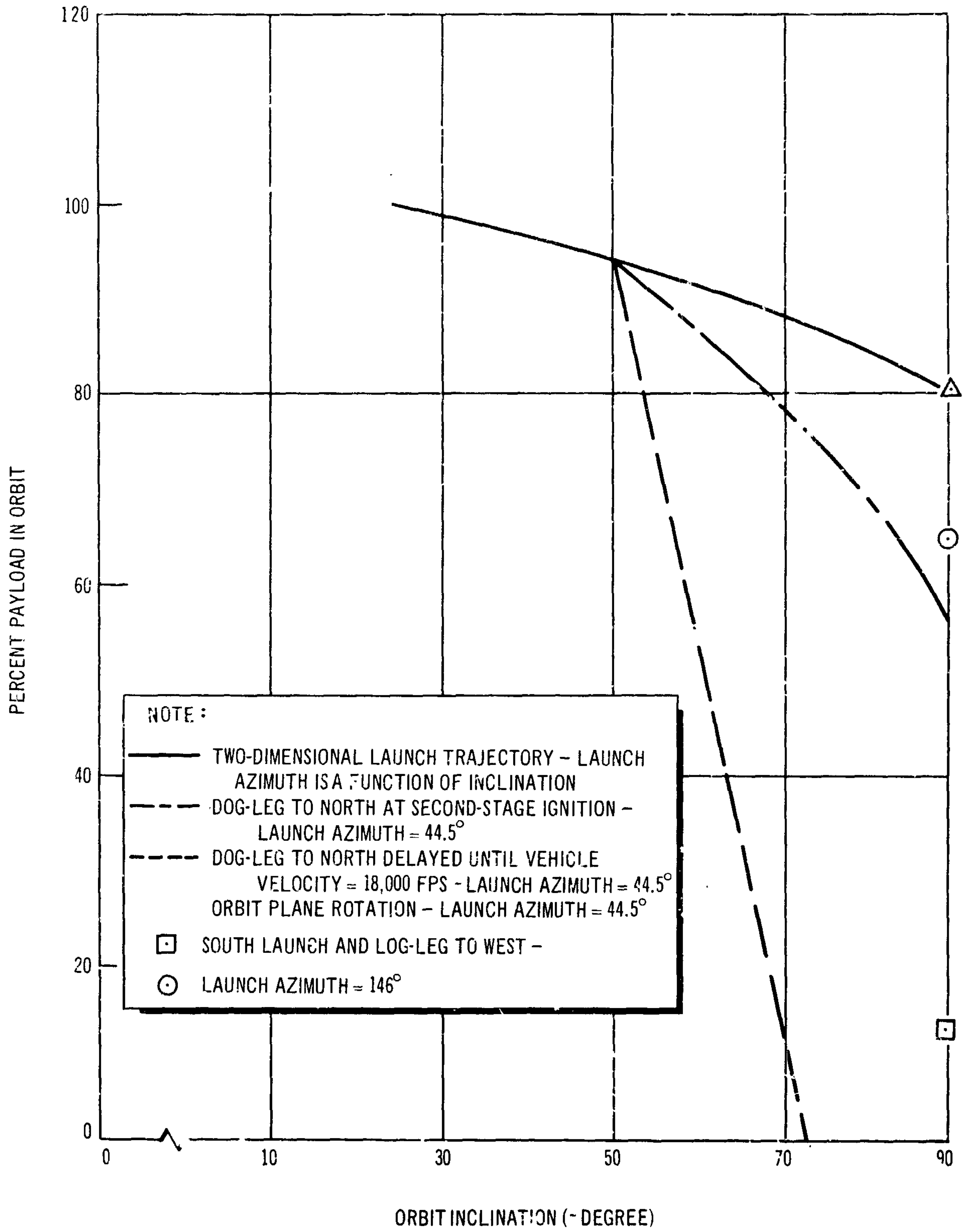


Figure 4-5. Effect of Orbit Inclination on Payload for a Variety of Launch Techniques (ETR Launch)

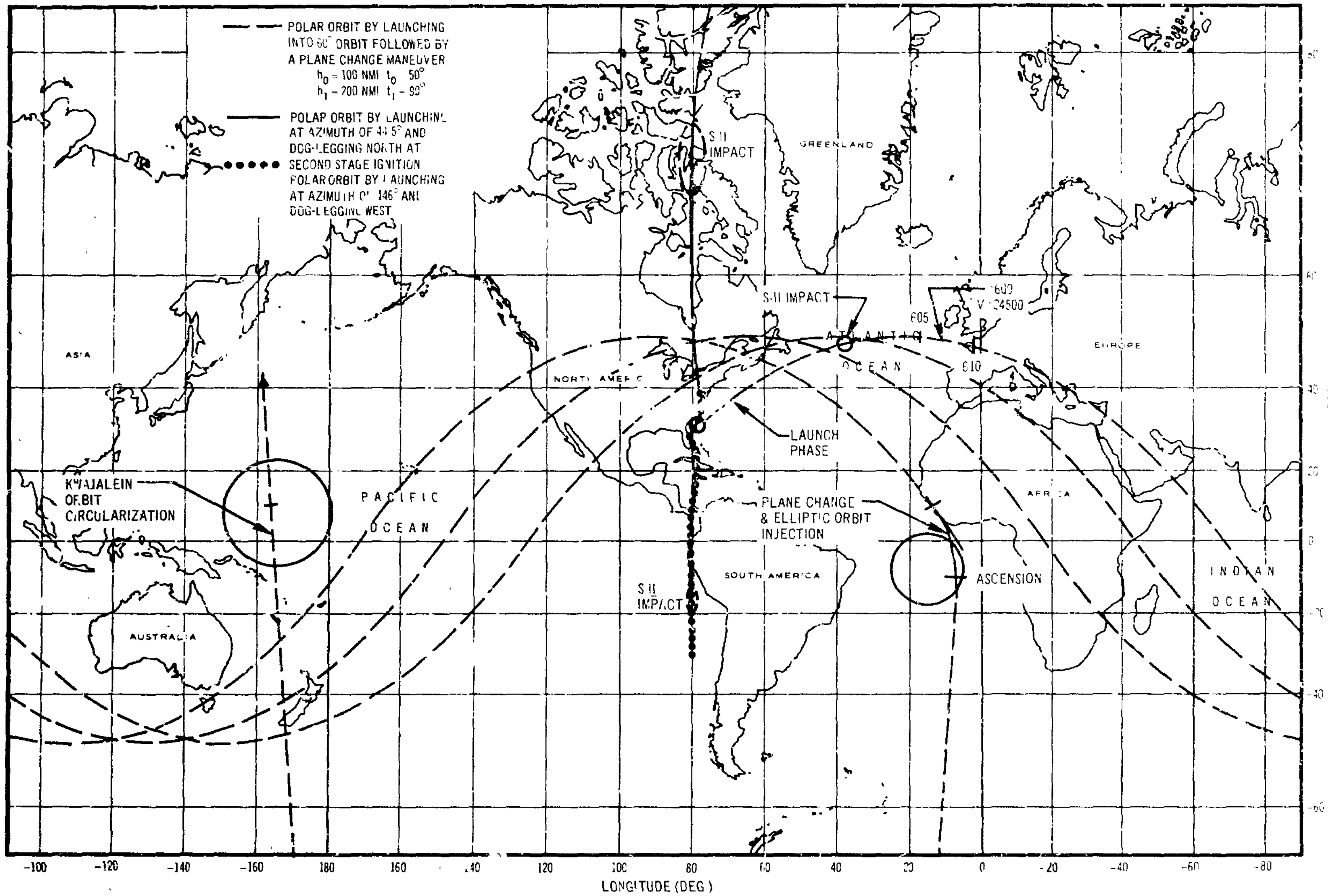


Figure 4-6. Launches into Polar Orbit

Figure 4-6 also shows a polar orbit ground trace obtained by launching at an azimuth of 146° and doglegging to the west at second stage ignition. At first inspection, it would appear that this trajectory is unacceptable from a range safety standpoint; however, it should be noted that this is merely a nominal case and does not represent the best trajectory possible. Techniques such as subranging and dogleg delays can shift the impact point trace so that only Cuba and Panama lie under the vehicle flight path. Launch trajectories of this type have been flown by Thor vehicles (Courier and Tircs Programs), and range safety waivers were obtained but never exercised by the Transit program. The favorable payload trade shown in Figure 4-5 by using this technique should not be hurriedly dismissed at this time. It should be noted that this represents a nominal and not a design trade factor. Performing some of the more exotic maneuvers will cause the payload factor to decrease; however, it should still provide greater payload capability than the orbit plane rotation technique.

The last method investigated consisted of a launch into a low altitude circular orbit inclined at 50° and then rotating the orbit plane in the vicinity of a nodal crossing. Figure 4-6 also shows the trace generated by this mission profile. The fourth descending node was selected for the orbit plane rotation maneuver to permit monitoring of the injection point by the Ascension Island radar. Because of the absence of significant range safety problems, this method of achieving polar orbit from Cape Kennedy was selected as the primary mode of operation. It is strongly urged that continued effort be applied toward minimizing the overfly and IIP problems associated with the 146° azimuth trajectory because of the increased payload capabilities associated with that launch mode.

The recommended mission profile consists of launching a fully-loaded, three-stage Saturn V and orienting the vehicle pitch plane at a 44.5° azimuth. After completely burning the propellants in the S-IC and S-II stages and after approximately 95 sec of burning on the S-IVB stage, the payload and the partially loaded S-IVB will be in a 100 nmi circular orbit inclined 50° to the equator. The S-IVB burns at suborbital velocities for 170 sec during the nominal lunar mission. The 75-sec reduction in burn time in the polar mission profile should not impose any modification requirements on the stage or its subsystems. Therefore, this mission profile will not present any major launch vehicle problems.

After about 4.75 hours of coast in the 100 nmi parking orbit, the S-IVB engine will be restarted and burned for an additional 370 sec. During this thrust phase, the orbit plane will be rotated to 90° inclination and the laboratory placed in an elliptic orbit with apogee at 200 nmi. After a 43-min. coast to apogee, the laboratory reaction control system will circularize the orbit. This latter maneuver can be monitored from Kwajalein as indicated in Figure 4-6.

4.2.2.2 Rendezvous Profile

The planar launch window for rendezvous in a polar orbit is solely a function of the time of arrival of the rendezvous spacecraft at the fourth descending node of the low altitude parking orbit. This assumes that the rendezvous spacecraft launch profile will closely parallel that of the laboratory. If the launch and orbit profile of the rendezvous spacecraft is exactly identical to that described by the laboratory, the two orbit planes will be coplanar. Early or late arrivals of the rendezvous spacecraft will produce planar separations, but the final inclination of both orbits will be the same. Note that this differs from the parallel plane launch technique where variations in the inclination, in other words, different launch azimuths, of the rendezvous orbit were used to reduce the total out-of-plane angle. Figure 4-7 shows the out-of-plane as a function of launch window achieved when only the Earth's rotation relative to target orbit plane is considered. Once the chase vehicle has been injected into its polar elliptic catch-up orbit, there are no relative regression effects to be considered.

The phasing portion of the rendezvous scheme will be identical to that described for the 50° rendezvous profile. This enables the preparation of a tabular input to determine the rendezvous velocity requirement.

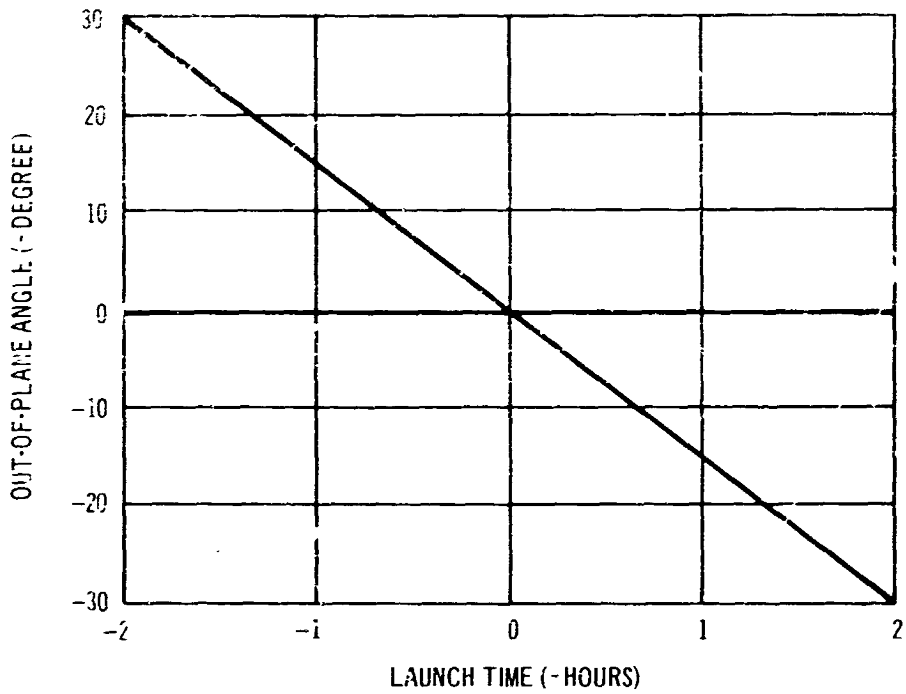


Figure 4-7. Out-of-Plane Angle as a Function of Launch Time (Polar Orbit)

Requirement	Velocity (fps)
Impulsive orbit circularization	194
Mechanization error pad	240
Docking impulse	50
Impulsive plane rotation	f(Launch window)
Error pad for plane rotation	K [f(Launch window)]

The summation of these quantities for each different value of launch window represents the total rendezvous velocity requirement. Figure 4-8 shows the percentage payload required for rendezvous propellant as a function of launch window. Two K values are shown, 0.1 and 0.01. Note that for a 10-min. launch window, approximately 13% of the Saturn payload must be in the form of rendezvous propellant. To obtain a launch window of 1 hour requires that about 40% of the payload be in the form of propellant. As in the case of the 50^{o} orbit inclination, the rendezvous launch window must be selected on the basis of reliability of achieving a launch rather than other trajectory

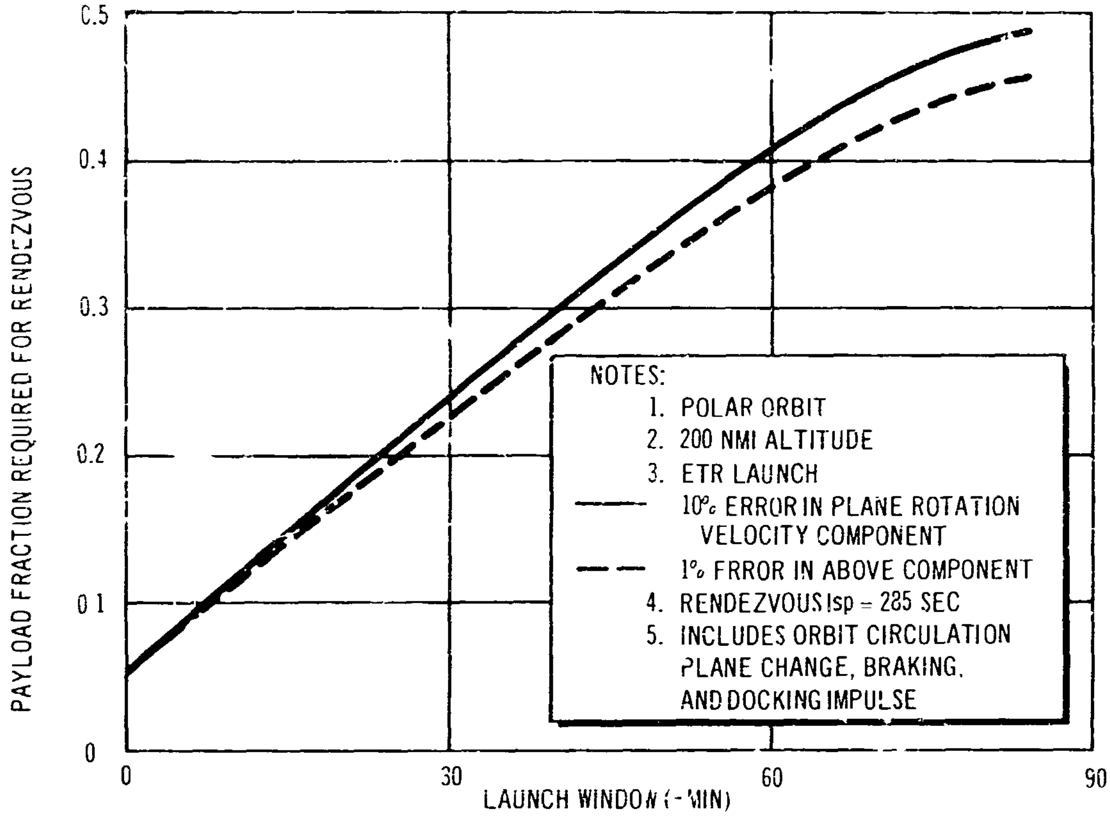


Figure 4-8. Rendezvous Payload Loss as a Function of Launch Window

mechanics considerations. Time did not permit an analysis of the time-line sequencing of the rendezvous mission and a description of the tracking requirements and capabilities.

4.2.3 Synchronous Orbit

4.2.3.1 Launch

The laboratory launch into a synchronous orbit inclined at 28.3° to the equator will be accomplished by a fully loaded three-stage Saturn V. The vehicle will be launched unmanned at an azimuth of 90° from true North from ETR. Following 129 sec of burning time on the S-IVB stage, the partially expended stage and the payload are injected into a 100 nmi circular parking orbit.

After approximately 54 min. of coast in this orbit, the S-IVB is reignited and injects the spacecraft into an elliptic orbit with apogee at 19,350 nmi. The coast time was selected to position the laboratory on a meridian passing through south Texas (98° west in this example). The coast time can be varied to position the orbit around any desired longitude. Figure 4-9 shows the coast time required in the parking orbit to achieve any desired longitudinal position from an east launch from the ETR. Approximately 115,000 lb of propellant are required for this impulse. Upon reaching the vicinity of apogee, following 5.25 hours of coast in the elliptic orbit, the J-2 engine on the S-IVB is started again and circularizes the orbit at synchronous altitude; 41,300 lb of propellant are required for this maneuver. The Earth trace of this launch profile is shown in Figure 4-10.

The initial S-IVB propellant loading includes that required for all burns, propellant vented overboard resulting from boil-off effects, and 5% contingency for flight performance reserves, propellant utilization, and trapped and residual propellants. The latter is a conservative estimate, and after a certain amount of flight experience with the Saturn V, a 3% contingency factor is more likely. This will result in a payload increase of about 3,200 lb.

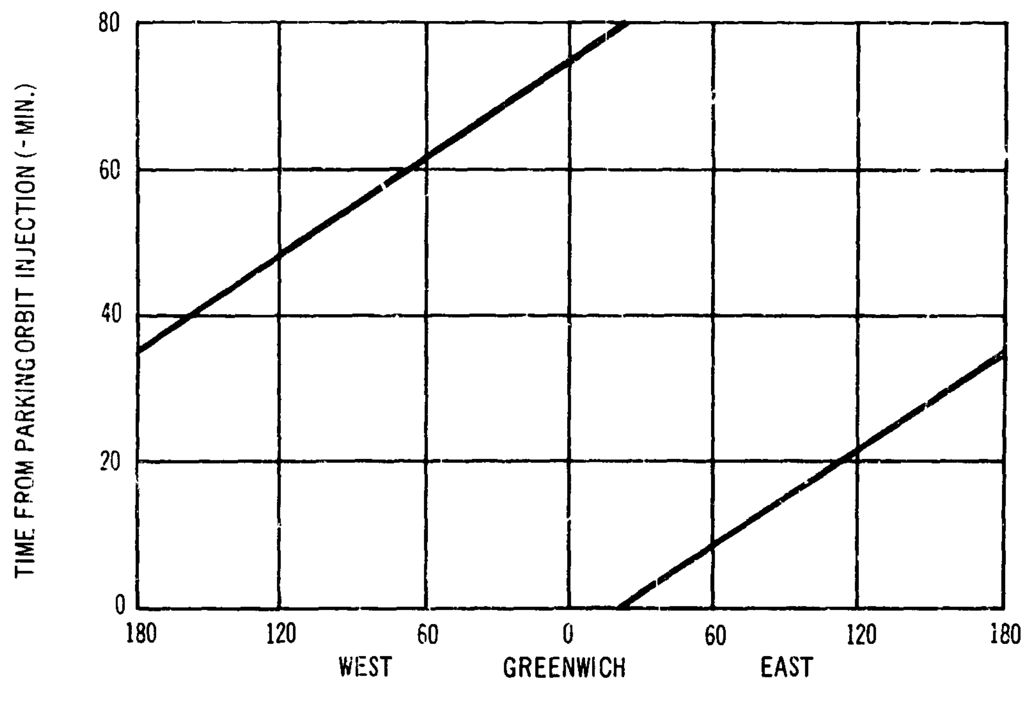


Figure 4-9. Effect of Coast Time in 100 nmi Parking Orbit on Final Position of Synchronous Satellite

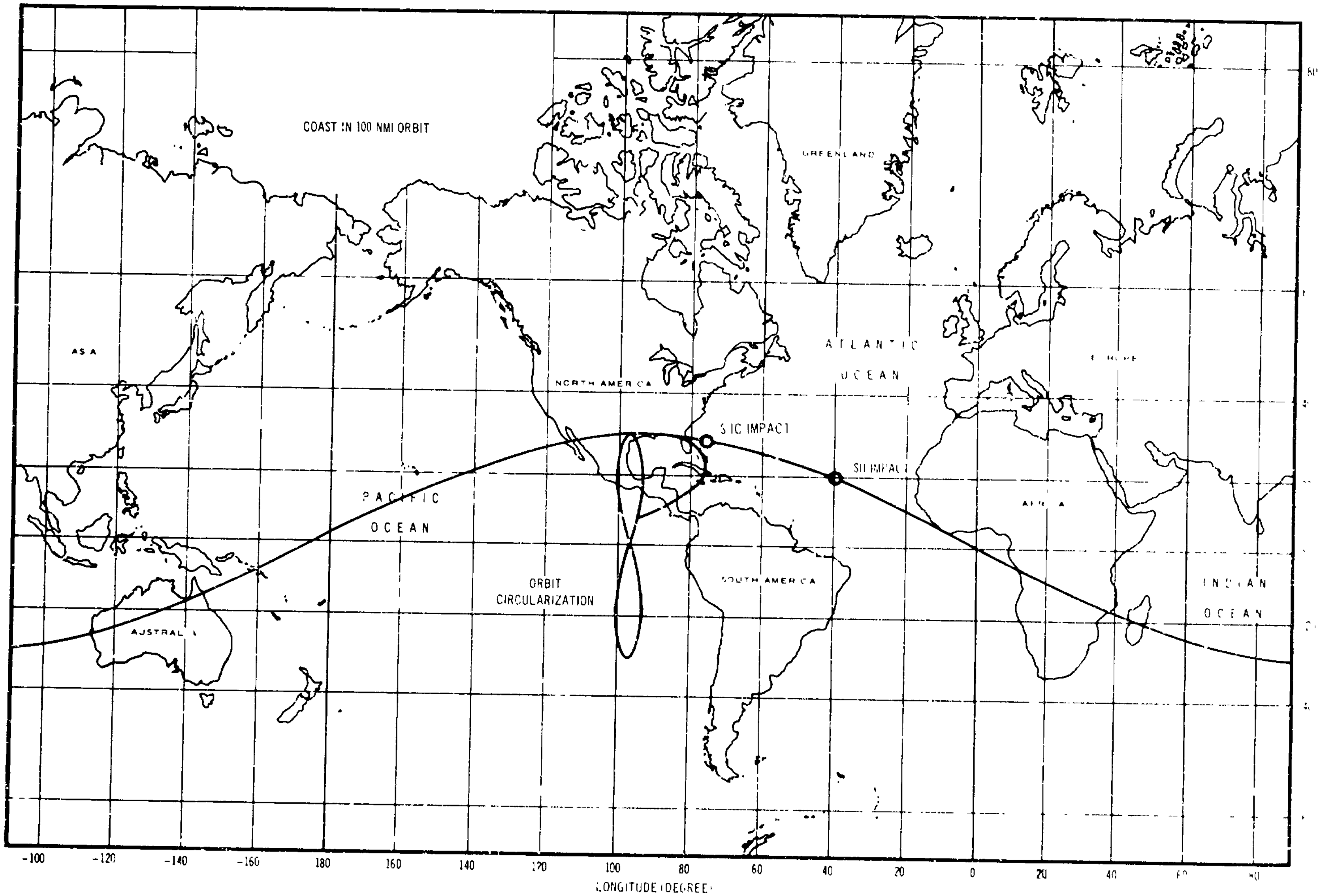


Figure 4-10. Saturn V Launch to Synchronous Orbit

The mission profile described herein requires two restarts of the J-2 engine on the S-IVB. The current lunar mission requires only one restart. This additional operational capability is well within the limitations of the hardware: however, tankage increases in the ullage system will be necessary to handle the additional propellant settling operation. This should prove to be a minor modification, and the greatly superior cutoff accuracies obtained through S-IVB versus S-II orbital injection will be of tremendous benefit in controlling the final orbital position of the laboratory and subsequent rendezvous missions.

An alternate mission profile requiring only one restart of the S-IVB can also be utilized to achieve a synchronous orbit. Detailed trajectory analyses required to determine the payload trades that may exist were not performed; however, the final amounts of payload in synchronous orbit should be comparable. A Saturn V with an off-loaded S-IVB is launched due east from ETR. At burnout of the S-II stage, the partially loaded S-IVB and the payload are in a circular orbit at 100-nmi altitude inclined at 28.3° to the equator. From this point on, the two mission profiles are identical.

4.2.3.2 Rendezvous

After the laboratory is positioned in the synchronous orbit with all systems operational, another Saturn V will be launched with a manned Apollo payload capable of rendezvous with the laboratory. The nominal launch trajectory for the rendezvous vehicle should be identical to that of the laboratory. Because the laboratory is in a synchronous orbit relative to a point on Earth (and the launch site), the nominal launch time (time of the day) for the rendezvous vehicle will be the same as that of the laboratory.

The rendezvous module will correct all the errors incurred during the three near-Earth powered flight phases: ground launch, boost into parking orbit, and injection into transfer orbit. For this mission, the major error sources are: (1) ground launch initiation time, (2) phasing orbit initiation time, that is, variation in powered flight duration, and (3) ignition and burning time during injection from the circular phasing orbit to the elliptic transfer orbit. A summary of the probable timing deviations for the Saturn V vehicle and the resulting phase angle and out-of-plane angle deviations are shown in Table 4-4. From this table, the effect of Earth oblateness is seen to be insignificant. In the range of interest, the phase and out-of-plane angle errors are linear functions of the timing errors. Therefore, a ground launch window of 2 min., an orbit injection variation of ±1 sec, and a total transfer time variation of ±8 sec results in a final orbit that is inclined approximately 0.12° to the laboratory's orbit with the chaser either in front or behind the laboratory about 0.68°. To eliminate the possibility that the chaser will lead the laboratory at synchronous orbit attainment, the transfer orbit injection will be initiated approximately 10 sec earlier than normal. This biased launch sequence results in the Apollo spacecraft lagging the laboratory by as much as 1.74°.

Because of the phase angle error, the rendezvous vehicle will thrust until its velocity is approximately 20 fps short of circular orbit velocity at synchronous altitude for each degree of phase angle lag. After one revolution (about 1 day) in this catch-up orbit, the phase lag has been corrected and a braking and docking maneuver is initiated.

The out-of-plane angle error is corrected after the rendezvous craft transfers to the catch-up orbit. This correction may be performed when the vehicle is near a geometric latitude of either plus or minus 28.5°. A correction in the Northern Hemisphere is recommended to provide extra time for the ground facilities to establish an accurate catch-up orbit ephemeris. This correction requires a velocity expenditure of about 180 fps/degree out-of-plane angle.

Table 4-4

SYNCHRONOUS ORBIT LAUNCH ERROR SUMMARY

Error Source (sec)	Sensitivity (deg/sec)		Error (deg)	
	$\frac{\delta\phi}{\delta t}$	$\frac{\delta i}{\delta t}$	$\Delta\theta$	Δi
Ground launch: 60	0.0003	0.002	0.018	0.12
Orbit initiation: 1	0.062	0.001	0.062	0.001
Burning time: 8	0.075	0.000125	0.60	0.001
Total			0.68	0.12

When the spacecraft reaches perigee of the catch-up orbit, a thrusting maneuver is performed to adjust the apogee altitude. Assuming that the integrating accelerometers provide a velocity cutoff accuracy of 0.1% for transfer from the circular phasing orbit, an apogee altitude error of ±80 nmi is possible. At perigee of the catch-up orbit, the apogee altitude is corrected with a velocity expenditure of 0.11 fps/nmi of apogee altitude error.

After completing one revolution in the catch-up orbit, the Apollo spacecraft is coplanar with the laboratory and at the same altitude. The two vehicles, separated by no more than 100 nmi, are in radar contact. A braking maneuver is then performed reducing the separation distance to 10 nmi and the relative velocity to 10 fps. At completion of this operation, a docking maneuver under visual control of the crew is performed. A summary of the impulses pertinent to the rendezvous profile described are listed in Table 4-5. The total velocity expenditure is 202 fps.

This rendezvous maneuver features the use of the S-IVB stage as the prime propulsion unit during rendezvous, thereby utilizing to the utmost the superior performance it affords. It should also be noted that a guidance mechanization scheme had not been mentioned until the separation distance was reduced to 100 nmi. It was assumed that ground tracking and computer facilities will provide all the inputs necessary to that point, and the internal guidance system will accept these inputs in flying the vehicle.

Table 4-5

RENDEZVOUS VELOCITY REQUIRED FOR SYNCHRONOUS MISSION

Error	Impulse (fps)
1. Fine adjustment into catchup orbit	20
2. Out-of-plane angle	22
3. Apogee altitude adjustment	10
4. Braking maneuver	100
5. Docking maneuver	50
Total	202

4.3 SUBSYSTEM ANALYSIS

4.3.1 Environmental Control and Life Support System (EC/LS)

The alternate missions have a major effect on the thermal balance of the EC/LS System. This balance is affected by changes in heat received and rejected by the EC/LS radiator at alternate orbit conditions. The primary effect is caused by changes in the heat influx to the radiator.

The baseline EC/LS System was found adequate to handle changes in heat influx encountered on the 50° and 90° low altitude missions. The influx reduction encountered on the synchronous mission requires that the radiator area be reduced to retain proper heat balance. This can be accomplished simply by removing 13 of the 41 circumferential radiator tubes.

4.3.1.1 Description of the Baseline System

The EC/LS subsystem is composed of the following operational groups of equipment:

1. Atmospheric supply.
2. Atmospheric purification.
3. Water management.
4. Waste management.
5. Compartment conditioning.
6. Cooling circuit.
7. Heating circuit.
8. Heat transport circuit.
9. Pumpdown circuit.

The total system function is to provide a proper atmosphere, adequate heat and ventilation, potable drinking water, efficient management of waste material, and the means to remove and conserve the atmosphere from portions of the laboratory. The EC/LS system was designed nominally for a crew of six, however, it can accommodate nine men with a negligible degradation in performance.

4.3.1.2 Mission Requirements--Orbital Considerations

The primary function of the EC/LS system is to provide a habitable environment for the crew so that they can accomplish the sophisticated experimental programs required by the mission. A secondary function is to maintain a suitable environment for the operation and experimental equipment contained within the laboratory. These functions are assumed not to change for the three orbits considered; therefore, the system changes required to accommodate the different missions can be expected to be minimal.

4.3.1.3 Subsystem Capabilities and Potential Changes

The baseline EC/LS system has the capability to accomplish the expanded mission-required functions since these functions are assumed the same for three orbits. The only equipment change required concerns the space radiator for the synchronous mission. The baseline radiator must be designed to reject the total heat generated within the laboratory plus the heat influx it receives from the sun and the Earth. Average heat influxes for the three missions are shown in Figure 4-11. The average indicates that the influx distribution over the radiator surface was averaged to provide the total influx. The heat influx encountered on the low altitude orbits is close to the radiator design point of 58.5 Btu/hour-sq ft, and no change is required. The average influx for the synchronous mission is seen to be 27.5 Btu/hour-sq ft. This large reduction must be accommodated by a change in the radiator area to avoid excessively low radiator fluid temperatures. The radiator area can be reduced to the value required for the synchronous mission by removing 13 of the 41 circumferential tubes. The radiator parameters required for the three missions are shown below:

Characteristic	50° and 90° Orbit	Synchronous Orbit
Number of circumferential tubes	41	28
Tube spacing	2.9 in.	2.9 in.
Tube diameter	0.20 in.	0.20 in.
Radiator length	10.0 ft	6.7 ft
Radiator weight (tubes + fluid)	317 lb	216 lb

Table 4-6

SOLAR CELL/BATTERY SYSTEM CHARACTERISTICS

Equipment or Characteristic	Type or Magnitude
System	
Average power	6.6 kW
Overload power (1 hour/day)	9.9 kW
Solar Cell Panel	
Type	Oriented flat plate
Solar cell type (and efficiency)	Silicon N on P (11.25 %)
Power rating (4 panels)	15.3 kW
Area	1,870 sq ft
Battery	
Type	Sealed silver cadmium
Replacement period	1 year
Depth of discharge	35 % nominal
Weight (lb)	
Solar cell panel	1,216
Batteries	774
Deployment mechanism	480
Power conversion equipment	337
Miscellaneous	340
Total	3,137

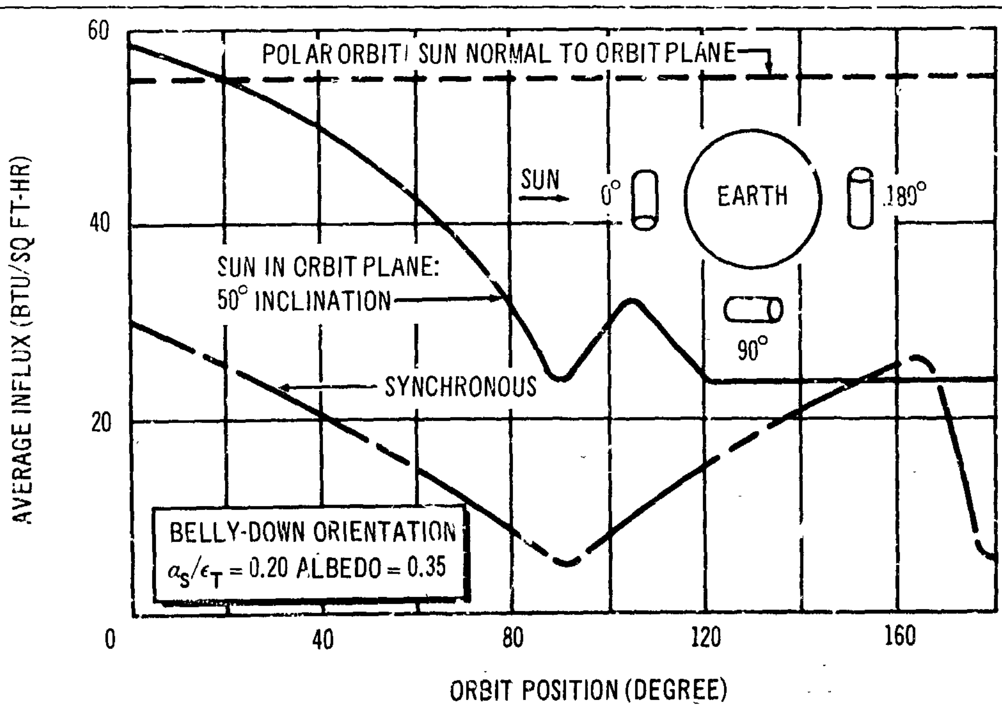


Figure 4-11. Average Heat Influx to MORL Radiator Surfaces

4.3.2 Electrical Power System

The solar cell battery baseline system is the power system discussed in this section. This system was changed to an Isotope Brayton cycle system midway in the study, and the effects of this change will be discussed in the Task IV report. It should be pointed out, however, that the analyses of the experiment loads required in this section and in Section 5.2 were not greatly affected by the power system supplied.

4.3.2.1 Baseline Power System Description

Characteristics of the baseline solar cell/battery power systems are summarized in Table 4-6. The system consists of four electrically independent solar cell panels, each of which can be switched to operate with any of the four battery/battery charger combinations. Any three solar cell panels and any three batteries can fail, and the system can still provide the manned emergency power requirement.

The inverters voltage regulators, and battery chargers are all conventional devices. All of the essential buses are redundant for maximum reliability. Extensive displays and controls are provided for the crew to permit failure analysis and alternate modes to bypass failed components.

The design requirements imposed upon the baseline MORL power source for raw electrical power (24 to 31 Vdc) may be summarized as follows:

Function	Power (kW)	
Housekeeping	3.77	
Experiments	2.00	
Subtotal		5.77
Reserve	0.83	
Total		6.60

Part of this raw power is used directly: the balance is converted to either regulated dc (28 ± 0.5 V), or 400-cycle ac. Housekeeping loads are defined to include all vehicle loads except experiment and includes about 790 W for maintaining the ferry vehicles on standby.

The power requirement is 5.77 kW. The power source is rated at 6.6 kW and provides a reserve of 0.81 kW for growth and contingencies. The power output can be reduced to 1.78 kW and still permit continued manned occupancy of MORL. This is defined as the minimum manned emergency power requirement.

Some of the experiments may require peak loads above the 6.6 kW average; a representative power requirement during peak periods has been established at 9.9 kW/for 1 hour once a day. A standby or emergency power source is not required with the solar cell/battery primary power source because of the inherent multiple redundancy and good partial power capability.

4.3.2.2 High Inclination Missions

Mission Requirements

The functions and requirements of the electrical power system were assumed to be the same as defined in MORL Phase IIa Report (Volume XVII, Electrical Power). Briefly summarized, the function of the system is to generate, regulate, and distribute electrical power to the various MORL subsystems, the docked ferry vehicles, and experiments. These requirements are given in Section 4.3.2.1.

The housekeeping functions are defined to include all vehicle functions except the experiments. There is presently no requirement for the 0.83 kW reserve, which is included for contingencies and growth of the housekeeping and experiment loads. The high inclination missions are assumed to have the same load profile as the baseline system, which is shown in Figure 4-12.

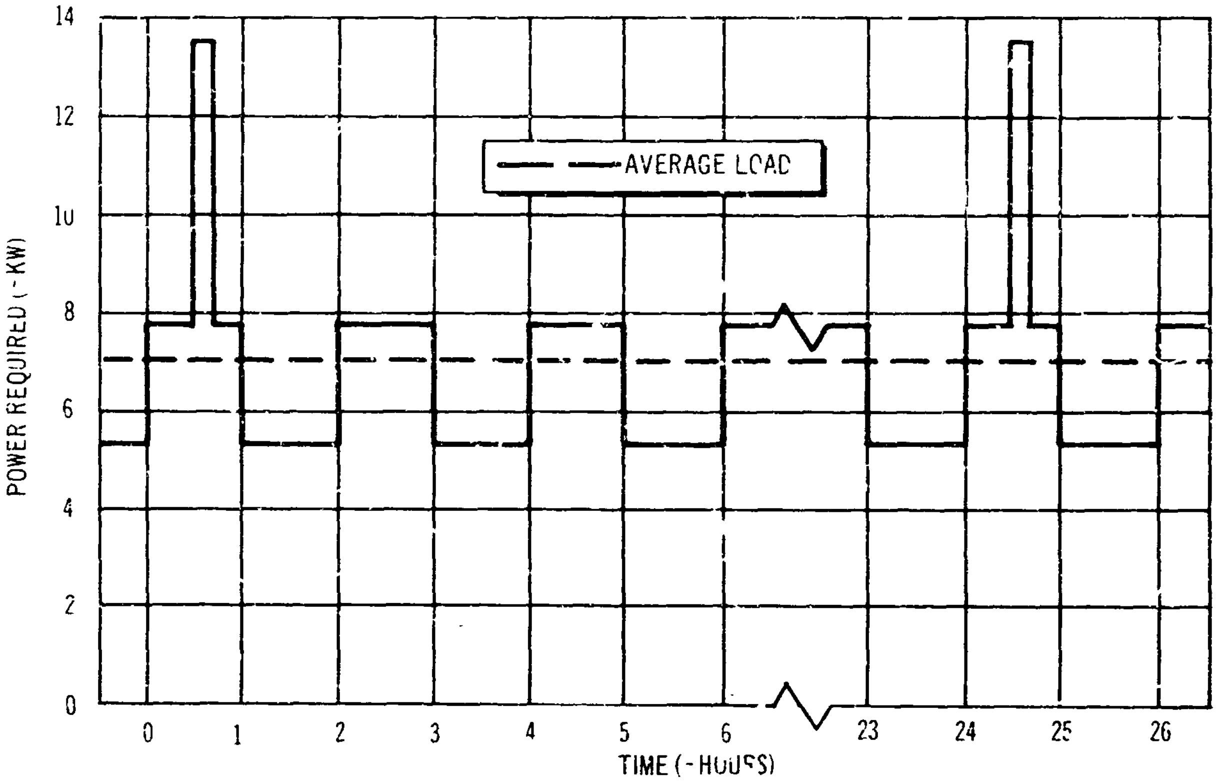


Figure 4-12. Design Electrical Power Load Profile

Subsystem Capability

The solar cell/battery system as defined above is suitable for the 50° and 90° inclination missions with virtually no changes. The solar cell panel area weight and the battery weight, which make up the bulk of the power system weight, are unchanged.

Solar flux and trapped electrons and protons increase in intensity at higher orbit inclinations. For 30- to 60-day missions, the total integrated flux from these particles has a negligible effect on the solar cell output. The degradation of the solar cell output for even more extended periods is not a serious problem. In a 5-year period, the solar cells will degrade 3.5% and 4.0% due to radiation for 50° and 90° inclinations, respectively. The degradations, as well as temperature degradation at the higher inclinations, were considered in the system design.

4.3.2.3 Synchronous Mission

Mission Requirements

The synchronous orbit is characterized by a favorable light/dark cycle for a solar cell power system. For the 19,350-nmi altitude 28.3° inclination orbit, the laboratory is in continuous sunlight except for two 18-day periods/year. Even in these unfavorable periods the laboratory is in darkness only 1.2 hours/orbit and in light 22.8 hours/orbit.

The electrical power requirements between launch and synchronous orbit injection would require a severe drain on the existing battery system because of the 7-hour duration. The solar cell panel will not be deployed until orbit injection because of the large g forces experienced during orbit injection. The power demand during the transfer orbit will require approximately 100 lb of silver-zinc batteries.

Subsystem Capability

While in the dark period, the battery system has a power capability of 3.5 kW at a 35% depth of discharge. The solar cell output during the light portion of the orbit is 15.3 kW. Of this, 3.77 kW are required for housekeeping loads, and 0.35 kW are required for charging the battery. The average power capability is then 14.3 kW. The power during the dark portion of the orbit could be increased by allowing a higher depth of discharge on the battery system. This would not have any deleterious effects because of the low number of charge/discharge cycles per day (1 compared to 16 for the low orbit missions). Solar flares and trapped electrons at a 19,350-nmi altitude will cause a negligible solar cell degradation for this mission.

4.3.3 Stabilization and Control System

The baseline Stabilization and Control System (SCS) is adequate to provide the attitude control and orbit keeping functions necessary to accommodate the three MORL missions of interest. The propellant consumption requirements and control moment gyro (CMG) size requirements for the 90° inclination and synchronous missions are less than for the 50° mission; thus, adequate capacity is retained with the baseline SCS.

4.3.3.1 SCS Description

The stabilization and control system is responsible for placing and maintaining the laboratory in the orientation required by each event or phase in the mission profile. A set of rate integrating gyros, aligned with the local vertical by an Earth horizon scanner, supplies the basic attitude error information. Control torques, needed to maneuver the laboratory or counteract dynamic disturbances, are supplied by a set of four control moment gyros (CMG's). A bipropellant reaction control system (RCS) is used to periodically dump momentum stored by the CMG's and to act as a backup attitude control actuator in the event the CMG's are inoperative. This propulsion system is also used to supply the energy needed to maintain altitude in the presence of aerodynamic drag.

The major requirements imposed on the SCS in the zero-g mode are associated with these events or functions:

1. Injection into orbit.
2. Orbit keeping or orbit altitude maintenance.
3. Rendezvous and docking.
4. Minimizing effects of external disturbances (aerodynamic drag and and gravity torques).
5. Solar cell panel orientation.
6. Counteracting the centrifuge torque.
7. Supporting experiment requirements.

4.3.3.2 Orientation

For the first three mission events listed, the Belly Down orientation is used. This holds for all three mission trajectories. In the Belly Down orientation, the laboratory yaw axis is aligned with the local vertical, and the longitudinal or roll axis is aligned in the orbit plane. For the fourth function, minimizing effects of external disturbances, this orientation is again the best, at least for the low altitude orbits.

For the synchronous orbit, aerodynamic and gravity gradient forces are reduced to a negligible amount; orientation does not have an important effect on dynamic disturbances.

Orientation requirements imposed by solar panels generally conflict with other functional requirements, particularly experiments. While the solar panels must obviously be pointed toward the Sun, the experiments may require different pointing in any orientation. Generally, however, pointing toward Earth surface objectives is required. The use of gimbals on the solar panel mechanism allows both requirements to be satisfied with the laboratory in the Belly Down orientation. However, during long periods in which no Earth-pointing experiments are scheduled, it is recommended that the Roll Solar orientation be used. In this orientation, the -X (roll) axis is pointed toward the sun, and the yaw axis is constrained to lie in the orbit plane. This permits the solar panels to remain fixed, eliminates solar panel shadowing, and reduces the impingement of RCS exhaust products on the solar panels.

4.3.3.3 Propellant and Control Moment Gyro Sizing

The effects of orientation on propellant consumption and CMG size are of primary importance since these items constitute the major weight elements in the SCS. Propellant consumption requirements may arise from both orbit keeping and attitude control functions. However, with the Belly Down orientation, it is possible to apply the attitude control torques so that the RCS engines thrust along the velocity vector direction and subtract from the orbit keeping impulse requirement. These torques are needed when the CMG's reach the limit of their momentum storage capability.

The orbit-keeping propellant requirement is a function of atmospheric density which varies with the solar cycle, the altitude, and the laboratory position in orbit relative to the diurnal bulge. Solar-cycle activity has the most important effect. Table 4-7 shows the propellant and momentum storage requirements for a typical configuration in a 50° inclination, 200 nmi altitude orbit and illustrates the effect of atmospheric density variation as a function of time.

4.3.3.4 Performance Requirements

As previously noted, the experiments impose the most difficult requirements on the SCS. The laboratory acts essentially as an experiment mounting platform and can provide various levels of control depending on the operating mode. This is discussed fully in Section 5.3.2.

Table 4-7

PROPELLANT AND MOMENTUM STORAGE REQUIREMENTS

Case: Belly Down Orientation with Solar Panels

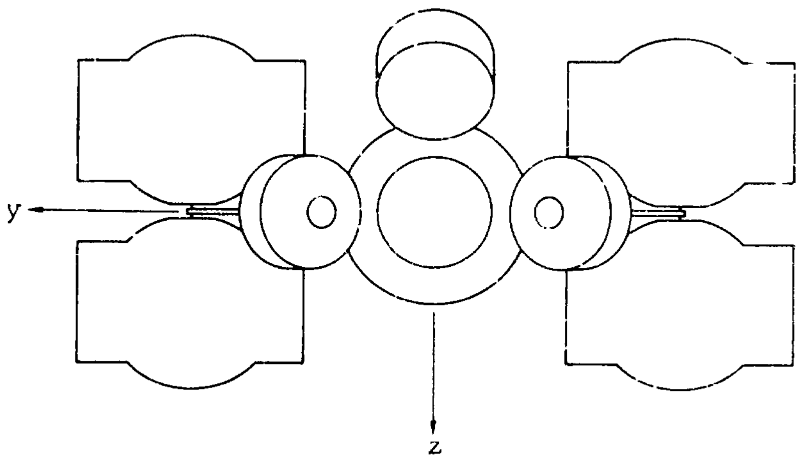
3 Stowed Modules as Shown:

Inertia Properties:

$I_x = 0.49 \times 10^6$ SL-FT^2 $\quad I_{xy} = 0$

$I_y = 0.63 \times 10^6$ SL-FT^2 $\quad I_{xz} = 0.042 \times 10^6$

$I_z = 0.77 \times 10^6$ SL-FT^2 $\quad I_{yz} = 0$



	Propellant			Momentum Storage					
				Momentum (lb-ft-sec)				System Weight (lb)	
Year	Orbit Keeping (lb/month)	Attitude Control (lb/month)	Combined Requirement (lb/month)	Pitch (lb-ft-sec)	Yaw	Combined Pitch and Yaw	Roll	Combined Pitch and Yaw	Roll
1969	261	290	290	250	880	910	3530	276	306
1970	144	248	248	250	490	540	3270	248	296
1971	65	218	218	250	220	330	3090	226	288
1972	32	206	206	250	110	270	3010	212	284
1973-1974	19	202	202	250	[illegible]5	260	2980	206	282

It can be concluded that the current SCS concept, which provides a basic stabilization platform and requires precision experiments to supply their own stabilized gimbal mounts (and, in some extreme cases, their own attitude and rate sensing as shown in Section 5.3), is adequate to meet performance requirements imposed by alternate missions. The major impact of alternate missions is dependent on the number and types of experiments chosen for the mission.

For pitch and yaw attitude control, only the aft firing pitch and yaw thrusters are used. This method provides the addition of linear and angular impulse. Thus, by activating one aft firing pitch engine, the pitch CMG can be desaturated and, with no additional propellant required, all or a portion of the orbit-keeping impulse can be applied. If this philosophy can be maintained, the total propellant required is equal to the larger of the two requirements, that is, either orbit keeping or attitude control. For the baseline configuration, the attitude control requirements are greater. If they are satisfied, adequate orbit-keeping capability is inherent. Orbit-keeping propellant for a baseline laboratory in a 90° orbit would be about 10% less than that shown in Table 4-7 because of decreased time in the diurnal-bulge region.

At synchronous altitudes, aerodynamic drag effects are negligible. Orbit-keeping (station-keeping) propellant requirements arise from orbit perturbations due to the sun, moon, and Earth. Those emanating from the Earth are due to the triaxiality of the Earth mass and would result in an oscillatory east-west drift of the satellite of up to 90° with a period of from 1 to 5 years if not corrected. The propellant required to negate this disturbing force is estimated to be 0.5 lb per day. The Sun and Moon cause precession of the laboratory orbit plane because the laboratory is not in an ecliptic orbit. If precise station keeping is required, approximately 12 lb of propellant per day are needed to counteract this effect. If it is not counteracted, the resulting change in orbit inclination is about 1° per year. For synchronous altitudes, the SCS is oversized in terms of momentum storage capability because of reduced external disturbance torques. However, the use of a momentum storage system of approximately the same size is recommended to eliminate the propellant requirement that would otherwise be needed for attitude control limit cycling and maneuvering.

4.3.4 Communications System

The mission requirements imposed on the communications system will be examined in this section. The experiment requirements will be discussed in Section 5.4. The baseline communications system was found to be adequate to support the 50° inclination mission requirements without change. To accommodate the 90° inclination mission, a tracking site, probably at Guaymas, must be added to the baseline system (Cape Kennedy and Corpus Christi) to provide ground-tracking capability for three consecutive orbits. This requirement must be fulfilled to meet the requisite navigation accuracies. The synchronous mission can be accommodated with the addition of an S-band rf system. This change is to provide proper bandwidth capability with the additional 25 dB space loss encountered at this transmission distance.

4.3.4.1 System Description

The communications/telemetry and ground support systems consist of three major functional groups:

1. Data Management Subsystem Group which performs the necessary data collection, storage, and processing operations. This group is composed of the following subsystems: T/M Data Acquisition, Tape Recording, Facsimile, File, Central Data Processing, and Data Adapter. The characteristics of the T/M Data Acquisition, Tape Recorder, and Computer Subsystems are listed in Tables 4-8, 4-9, and 4-10, respectively.
2. RF Subsystems Group which implements the various information exchange links (both ground and space terminals). This group is made up of the following subsystems: Telemetry, Voice Communications, Television, Tracking Aid, Digital Command, Antenna, and Film Projection/Scanner. The characteristics of these subsystems are summarized in Table 4-11.
3. Ground Network which considers the location and number of ground terminals. The baseline network is composed of the Cape Kennedy and Corpus Christi sites located at the following coordinates:
   A. Cape Kennedy: Latitude 28°28 min.; Longitude (E) 279°25 min.
   B Corpus Christi: Latitude 27°39 min.; Longitude (E) 262°27 min.

For the 50° inclination, 200 nmi mission, the baseline network results in the 5-day duty cycle given in Table 4-12.

Table 4-8

MORL BASELINE DATA ACQUISITION CHANNEL CHARACTERISTICS

Total Channels	Spare Channels	Sample Rate (Samples/Min.)	Total Bits/Sec	Spare Bits/Sec
		Low-Rate Digital Channel		
240	88	1	32	12
90	37	10	120	49
121	41	60	968	328
32	0	300	1,280	0
483	166		2,400	389
		Medium-Rate Digital Channel--Mode A		
12	7	2,400	3,840	2,240
16	3	7,200	15,360	2,880
28	10		19,200	5,120
		Medium-Rate Digital Channel--Mode B		
12	9	2,400	3,840	2,580
16	4	7,200	15,360	3,840
28	13		19,200	6,420

Table 4-9

BASELINE DIGITAL TAPE RECORDER CHARACTERISTICS

	Low-Rate Recorder	Medium-Rate Recorder
Mode	Continuous	Intermittent
Tape width	1/2 in.	1/2 in.
Number of heads	8	8
Input rate	300 words/sec	2,400 words/sec
Record speed	15/32 in./sec	3.75 in./sec
Readback speed	15 in./sec	15 in./sec
Playback to record speed ratio	32 to 1	4 to 1
Tape length	2,400 ft	2,400 ft
Maximum record time	17.1 hours	128 min.
Bit density	640 bpi	640 bpi
Output rate	76,800 bits/sec	76,800 bits/sec
Full tape playback time	32 min.	32 min.

4.3.4.2 Mission Requirements and Accommodations Analysis

Data Management Subsystem Group

The collection, storage, and processing of data necessary for the mission objectives has not significantly changed from the Phase IIa analysis. These requirements are listed in Table 4-13. The requirements imposed on this subsystem group by experiments will be discussed in Section 5.4.

RF Subsystems Group

The important mission requirements imposed in the RF Subsystems Group are related to the influence of orbital altitude on rf link gain margins. For the 50° inclination and 90° inclination missions, the orbital altitude is 200 nmi, which is the same as considered in Phase IIa for baseline systems design. Therefore, no change in requirements is imposed. However, for the synchronous mission, the additional communications distance (19,350 nmi as compared to 1,100-nmi maximum range for the 200-nmi mission)

Table 4-10

BASELINE COMPUTER CHARACTERISTICS

Equipment or Characteristic		Type or Magnitude
Computer		Stored program, general purpose, serial fixed point, binary;
	Operating speed	Add-subtract and multiply-divide simultaneously
		12,000 equivalent add-type operations/second.
	Add time, accuracy	84 μ sec, 26 bit,
	Multiply time, accuracy	336 μ sec, 24 bit,
	Divide time, accuracy	672 μ sec, 24 bit.
Clock		500,000 bps, 35.7 kc memory cycle rate
Storage Capacity		8,192 twenty-six-bit words (expandable in 4,096-word sections to 32,768 words total).
Input-output		External-computer programmed I/O control
Packaging		Electronic page assemblies, two 4,096-word memory assemblies

Table 4-11

RF SUBSYSTEM CHARACTERISTICS

Subsystem	Characteristics
Telemetry	Provides frequency division multiplexing and transmission to ground.
Voice communications	Provide two-way voice communications between MORL and ground or logistics vehicle.
Television	Provides on-board and external observation with three cameras and three monitors. Provides black and white pictures at 30 frames per sec, 525 scan lines per frame, 500 elements per line, and a 4.3 aspect ratio.
Tracking aid	A UHF acquisition and beacon/command 2 W transmitter in the 225-260 mc range. A C-band transponder with peak output of 1,000 W which is compatible with FPQ-6, TPQ-18, FPS-16, and MSQ-26 radars.
Digital command	Receives ground commands by a dual receiver operating in the 406 to 450 mc region.
Antenna	Consists of VHF/UHF, S-band, and C-band antennas.
Film projection/scanner	Has the capability of in-flight film projection and/or conversion to an analog signal.

Table 4-12

BASELINE GROUND NETWORK COVERAGE DUTY CYCLE (5 DAYS) (page 1 of 2)

Notes: Orbit altitude = 200 nmi
Inclination angle = 50°
Minimum elevation angle = 5°
Orbit No. 1 starts at orbital altitude with latitude 28° 48 min., Longitude 80° 58 min.

Day	Orbit	Cape Kennedy (Min.)	Corpus Christi (Min.)	Redundant (Min.)	Total Nonredundant (Min.)	Total Usable (Min.)
1	1	3.84	2.58	----	6.42	6.42
	2	----	4.9	----	4.90	4.90
	10	7.35	----	----	7.35	7.35
	11	6.25	7.75	3.83	6.25	10.08
	12	----	3.92	----	3.92	3.92
	15	5.33	1.75	1.33	4.42	5.75
	16	1.92*	----	----	1.92	1.92
Total		24.69	20.92	5.16	35.18	40.34
2	16	0.92	4.25	0.92	3.33	4.25
	17	5.08*	3.42*	3.42*	1.66	5.08
	18	----	3.00	----	3.00	3.00
	25	4.92	----	----	4.92	4.92
	26	7.58	7.00	4.33	5.92	10.25
	27	----	6.58	----	6.58	6.58
	30	5.58	----	----	5.58	5.58
	31	3.17	5.42	3.17	2.25	5.42
	32	4.50*	1.25*	1.25*	3.25	4.50
Total		31.75	30.92	13.09	36.49	49.58
3	32	----	1.67	----	1.67	1.67
	33	----	5.25*	----	5.25	5.25
	41	7.67	3.58	3.00	5.25	8.25
	42	5.25	7.67	3.17	6.58	9.75
	43	----	0.92	----	0.92	0.92
	45	1.33	----	----	1.33	1.33
	46	4.75	4.17	2.83	3.25	6.08
	47	2.83*	3.58	----	6.41	6.41
	48	1.83	2.42*	1.83	0.59	2.42
Total		23.66	29.26	10.83	31.25	42.08

*Continuation of preceding contact

Table 4-12 (page 2 of 2)

Notes
Orbit altitude = 200 nmi
Inclination angle = 50°
Minimum elevation angle = 5°
Orbit No. 1 starts at orbital altitude with latitude 28° 48 min., Longitutde -80° 58 min.

Day	Orbit	Cape Kennedy (Min.)	Corpus Christi (Min.)	Redundant (Min.)	Total Nonredundant (Min.)	Total Usable (Min.)
4	48	2.33	1.75	1.75	0.58	2.33
	56	6.42	----	----	6.42	6.42
	57	7.17	7.50	4.33	6.00	10.33
	58	----	5.67	----	5.67	5.67
	61	6.00	----	----	6.00	6.00
	62	2.25*	5.00	2.25	2.75	5.00
	63	4.83	2.33*	2.33	2.50	4.83
Total		29.50	22.25	10.66	29.92	40.58
5	63	----	0.42	----	0.42	0.42
	64	----	5.33*	----	5.33	5.33
	72	7.83	5.67	4.00	5.50	9.50
	73	7.33	3.75	2.08	6.92	9.00
	76	3.92	----	----	3.92	3.92
	77	4.08	5.58	3.75	2.17	5.92
	78	3.67*	2.83	----	6.50	6.50
	79	----	3.08*	----	3.08*	3.08*
Total		26.83	26.66	9.83	33.84	43.67
Grand Total:		136.43	129.[illegible]9	49.57	166.68	216.25

*Continuation of preceding contact

Table 4-13

BASIC DATA ACQUISITION REQUIREMENTS

Item Sample Rates	1/Min.	10/Min.	1 Sec	Medium Rate Other	Medium Rate Other	Analog
1. Life support, environmental control, space suit	27, 2 *	6	8			
2. Power system	41, 12*	8				
3. Attitude control	3	2, 11*	34, 16*			
4. Vehicle and appendages	62	1, 11*		6 at 10/sec		
5. System electronics	6	26	18			
6. Computer			8, 1 *	1 at 40/sec		
7. Physiological	6	6	7	2 at 15/sec 1 at 3/sec	3 at 150/sec 3 at 250/sec 1 at 480/sec	1 analog 2 kc
8. Acoustical and vibrational						2 analog 1 kc
9. Unmanned checkout						2 analog 2 kc
Power group	60					
Life support	23					
Attitude control	40					

* Discretes

imposes an additional 25 dB space loss. The baseline system cannot accommodate this additional loss.

Ground Network

The basic parameter on which ground network accommodation of on-orbit operational requirements is measured is the coverage duty cycle resulting from the sites that comprise the network. The duty cycle characterizes the opportunities and durations for tracking, command, telemetry, and voice communication. It therefore has a significant influence on the ground support systems capability to satisfy requirements relative to these factors. For the 50° inclination mission, the duty cycle factors resulting from the baseline network are as follows:

1. Average usable contact time per day: 43.25 min.
2. Average occultation period: 5 orbits.
3. Maximum occultation period: 9 orbits.
4. Average number of successive orbit contacts: 3 orbits.
5. Average contact duration: 5.67 min.

For the polar mission the duty cycle factors are given in the first row (baseline network) of Table 4-14. The requirements and the level of accommodation are as follows:

Tracking

Ground tracking is the basis of the baseline navigation philosophy. The network requirement associated with tracking is defined in terms of the tracking duty cycle necessary to support the navigation accuracy requirements. The various levels of operational navigation accuracy requirements were determined in Phase IIa and are repeated in Table 4-15. No change has been indicated in these requirements. To satisfy these accuracies, considering the baseline tracking and prediction capabilities, the following tracking duty cycle requirements were imposed:

1. At least one tracking opportunity per orbit for three successive orbits
2. A command opportunity on the succeeding orbit.
3. A succeeding occultation period of no greater than 13 orbits.

Table 4-14

NETWORK DUTY CYCLE FACTORS FOR POLAR ORBIT

Network	Average Usable Contact Time Per Day (Min.)	Average Occultation Period (Orbits)	Maximum Occultation Period (Orbits)	Average Number of Successive Orbit Contacts (Orbits)	Average Contact Duration (Min.)
Baseline: Cape Kennedy Corpus Christi	28	5	6	2	5.59
Cape Kennedy Corpus Christi Hawaii	44	2	3	2	5.88
Cape Kennedy Corpus Christi Cuaymas	35	5	5	3	5.86
Cape Kennedy Corpus Christi Hawaii Guaymas	51	2	3	3	5.87

Table 4-15

NAVIGATION SYSTEM REQUIREMENTS (OPERATIONAL)

Mode Maneuver	Navigational Accuracy Required (nmi)
Rendezvous	10
Orbit keeping	1
Cargo module deorbit	50
Laboratory deorbit	50
Data capsule deorbit	2
Ferry-craft deorbit	2

For the 50° inclination mission, the latter requirements are easily met if both baseline sites are considered (this implies that the back-up tracking capability proposed in Phase IIa for Corpus Christi be upgraded to primary status).

The first two requirements indicate the necessity for contacts on four successive orbits. This precise requirement cannot be met by the baseline network. However, contacts by both sites during a single orbit occur frequently enough to insure three tracking opportunities during two successive orbits and a succeeding command opportunity. Additionally, because the average navigation accuracy between ground up-dates primarily is a function of prediction filter inaccuracies rather than tracking inaccuracies, it is concluded that the above method of insuring tracking opportunites will not reduce the average navigation accuracy, particularly when prediction is necessary for only an average of 5 orbits rather than the 13 indicated in Phase IIa. Therefore, the baseline network is considered satisfactory relative to the tracking requirements for operational purposes.

Another network requirement is imposed by tracking, in other words a minimum acceptable contact duration above 5° elevation. A minimum satisfactory contact time is approximately 3 min. As indicated previously, the average contact time for the baseline network is approximately 6 min. The individual contact times are shown in Table 4-12.

Examination of Table 4-14 revealed that the baseline communications system cannot fully accomodate the polar mission requirements. The average number of successive orbits in which tracking contacts can be made is only two, one less than the requirement. The maximum period of occultation is six orbits, which is satisfactory since 13 are allowed.

Command

From a network point of view, the primary tracking duty cycle considerations also apply to command responsiveness. For one of the operationally imposed command responsibilities (in other words, orbit-keeping commands) the tolerance on command opportunity is relatively broad and should easily be satisfied by the baseline network. Navigation up-date digital data impose additional network command requirements. The baseline responsiveness to this requirement was discussed above.

Telemetry

Telemetry dump opportunities sufficient to eliminate the possibility of PCM tape overflow establish the primary network requirements caused by telemetry. For continous recording (low-rate channel) at the prescribed record rate of 15/32 in. per sec for 2,400 ft of tape, approximately 17 hours (11 orbits) of recording time is possible. This establishes the maximum acceptable occultation period and is within the capability of the baseline network. Dump time required for the 2,400 ft of tape, played back at a speed of 15 in. per sec, is 32 min. Therefore, the network must facilitate at least 32 min. of dumping time every 17 hours or 45 min. per day.

As shown previously, the average dump time per day for the 50° mission afforded by the baseline network is 43.25 min. which, although close, is not sufficient. For the polar case, the dump time per day is only 28 min. which, of course, cannot accommodate the above requirements.

Voice Communication

The most important network factor relative to voice communication is the number of contact opportunities available. No specific requirement has been established. However, for emergency situations it is desirable to have at least one contact per orbit. This is not possible with the baseline network, which facilitates a one contact per orbit situation for only an average of three out of every eight orbits. Phase IIa prescribed an emergency nontracking network composed of MSFN stations. A similar network was derived for the 50^{o} inclination mission as follows:

The orbits on which contact can be made for each MSFN ground station are indicated by an X in Table 4-16. Those orbits covered by the baseline system (Cape Kennedy and Corpus Christi) were assumed accounted for and eliminated. These were orbits 1, 2, 10, 11, 12, 15 through 18, 25 26, 27, and 30 through 33 as shown in Table 4-16. The remaining 21 orbits can be covered by activating more ground stations as shown. The more important stations are listed below with the orbit coverage for emergency communications.

Ground Stations in Addition to Baseline	Number of Orbits Covered	% of the 21 Orbits
Hawaii	11	53%
Canary Islands	8	38%
Kano	9	43%
Hawaii + Canary Islands	18	86%
Hawaii + Kano	16	76%
Hawaii + Canary Islands + Kano	20	95%

It is noted that relatively few sites are required for emergency purposes.

4.3.4.3 System Modifications

As discussed earlier, no new mission requirements are imposed on the Data Management Group. Therefore, no modifications are considered here. All

Table 4-16

EMERGENCY VOICE STATIONS ORBIT COVERAGE

Legend X Voice contact

⊗ Indicates opportunities for the most logical additional sites.

⊠ Single identified need for Bermuda.

Orbit	Cape Kennedy	Corpus Christi	Canary Island	Hawaii	Kano	Bermuda	Guaymas	Muchea
1	X	X				X	X	
2		X					X	
3				⊗			X	
4				⊗				
5				⊗				
6					⊗			
7			⊗					
8			⊗					
9						⊠		
10	X					X		X
11	X	X				X	X	X
12		X	X				X	
13			⊗	⊗	⊗	X		
14			⊗	⊗	⊗	X		X
15	X	X				X		X
16	X	X				X	X	X
17	X	X					X	
18		X					X	
19				⊗				
20				⊗				
21					⊗			
22					⊗			
23			⊗					
24			⊗					
25	X					X		X
26	X	X				X		X
27		X	X		X		X	
28			⊗		⊗		X	
29			⊗	⊗	⊗	X		
30	X		X			X		X
31	X	X					X	X
32	X	X					X	
33		X					X	
34				⊗			X	
35				⊗				
36				⊗	⊗			
37					⊗			

changes to the baseline Data Management Group are discussed in Section 5.4. For the rf group, the only required modification of the baseline system is for the synchronous case. The synchronous mission is unique from the others considered in its implications on the communications/telemetry and ground support systems.

The increased orbital altitude (19,350 nmi as compared to 200 nmi) increases the rf propagation loss by approximately 25 dB, which obviates the use of omnidirectional vehicle antenna. On the basis of integration and operational complexity, the number of directional antennae which would be necessitated by the baseline rf subsystem configuration indicates the need for a unified rf carrier concept to permit a single antenna. A system operating at least at S-band is desirable both from the standpoint of antenna size and because NASA ground terminals for the Apollo unified S-band system exist. An adaptation of this system (primarily modifications to the vehicle system) is therefore proposed for the MORL synchronous mission.

Ground sites identified for unified S-band systems are:

1. Cape Kennedy.
2. Antigua.
3. Ascension Islands.
4. Bermuda.
5. Carnarvon.
6. Hawaii.
7. Guaymas.
8. Guam.

Although a large number of sites are available, only one site is required to support the on-orbit aspects of the MORL mission because a single ground site can provide continuous coverage of a vehicle at synchronous altitude (assuming, of course, that the subsatellite point is reasonably stable and properly oriented relative to the site). Aside from the advantages of requiring only one ground site, the implication of relative positional stability on voice communications, telemetry, and tracking are obvious particularly if the unified rf carrier concept is used. Time-sharing of the radio bandwidth for the various links, taken separately or in selected groups, is feasible. Thus, for instance, the radio bandwidth could be used entirely for high quality TV or the transmission of the analog representation of high resolution photographs (assuming the necessary film scanner resolution is available). Alternatively, the same bandwidth could be used for extremely high bit rate pulse code modulation. This, however, assumes the availability of sufficient readout speeds for the TLM storage device or frequently multiplexing the outputs of a large number of relatively slow readout storage devices, like tape recorders, onto subcarriers. Continuous tracking over a relatively long period of time with the attendant improvement in ephemeris accuracy is possible, again within the same bandwidth.

The possible improvement in system responsiveness is highlighted in the following areas:

1. RF subsystems group.
2. Ground network.
3. Data storage.

Table 4-17 indicates the duty cycle factors for several expanded networks for the 50° inclination mission. It can be seen that the Ken-Tex-Haw network (first row) satisfies all of the operational requirements. For the polar mission, this network is not satisfactory (see Table 4-14, row 2) and, therefore, the further network expansion (for example, Guaymas) is necessary for the accommodation of operational requirements. Further network evaluation is necessary to result in an optimum configuration.

4.3.5 Structures/Configuration System

The baseline structure was examined and found to be adequate to withstand the loads present on all three missions. Some minor configuration changes are required for the MORL to be compatible with the polar and synchronous missions. These changes are in the hangar section and are designed to make the MORL compatible with the logistics system attach method.

Table 4-17

DUTY CYCLE FACTORS FOR EXPANDED GROUND NETWORKS (50° MISSION)

Network	Average Usable Contact Time Per Day (Min.)	Average Occultation Period (Orbits)	Maximum Occultation Period (Orbits)	Average Number of Successive Orbit Contacts (Orbits)	Average Contact Duration (Min.)
Cape Kennedy Corpus Christi Hawaii	66	3	4	8	5.34
Cape Kennedy Corpus Christi Guaymas	57	5	9	5	5.13
Cape Kennedy Corpus Christi Guaymas Hawaii	80	4	4	10	5.55
Baseline: **Cape Kennedy** **Corpus Christi**	43	5	9	3	5.67

Radiation shielding must be added for all three missions. The shield requirements for the 50° and 90° inclination orbits can be accommodated by increasing the gage of the material in certain areas or by adding polyethylene to the basic structure. The shield requirements for the synchronous mission are excessive (greater than 20 tons) and cannot be accommodated with the present MORL concept.

4.3.5.1 Configuration/Structures Description

Configuration

The baseline laboratory external and internal configuration was defined in Phase IIa, Volume XI, Laboratory Configuration and Interiors, Report No. SM-46082, and is shown in Figure 4-13.

The configuration basically consists of two floors and a hangar deck within the pressure shell. The top floor is used as the living quarters, the bottom floor for experimentation and vehicle operation, and the hangar deck for storage and deployment of experimental equipment. The hangar also contains an experimental airlock and other equipment necessary for space experimentation.

Structure

The structure consists of three principal elements as shown in Figure 4-14: (1) an external load-carrying shell that also supplies meteoroid penetration protection, (2) a pressure shell with common bulkhead that separates the laboratory into two separate pressure areas, and (3) the internal support structure that integrates the consoles, partitions, floors, and ceilings.

4.3.5.2 Configuration Analysis

50° Inclination, 200-nmi Mission

The launch and orbit configurations for the 50° inclination orbit missions are shown in Figure 4-15. On the 50° inclination mission, the laboratory is launched unmanned by an S-IB booster. A combination Apollo/cargo module

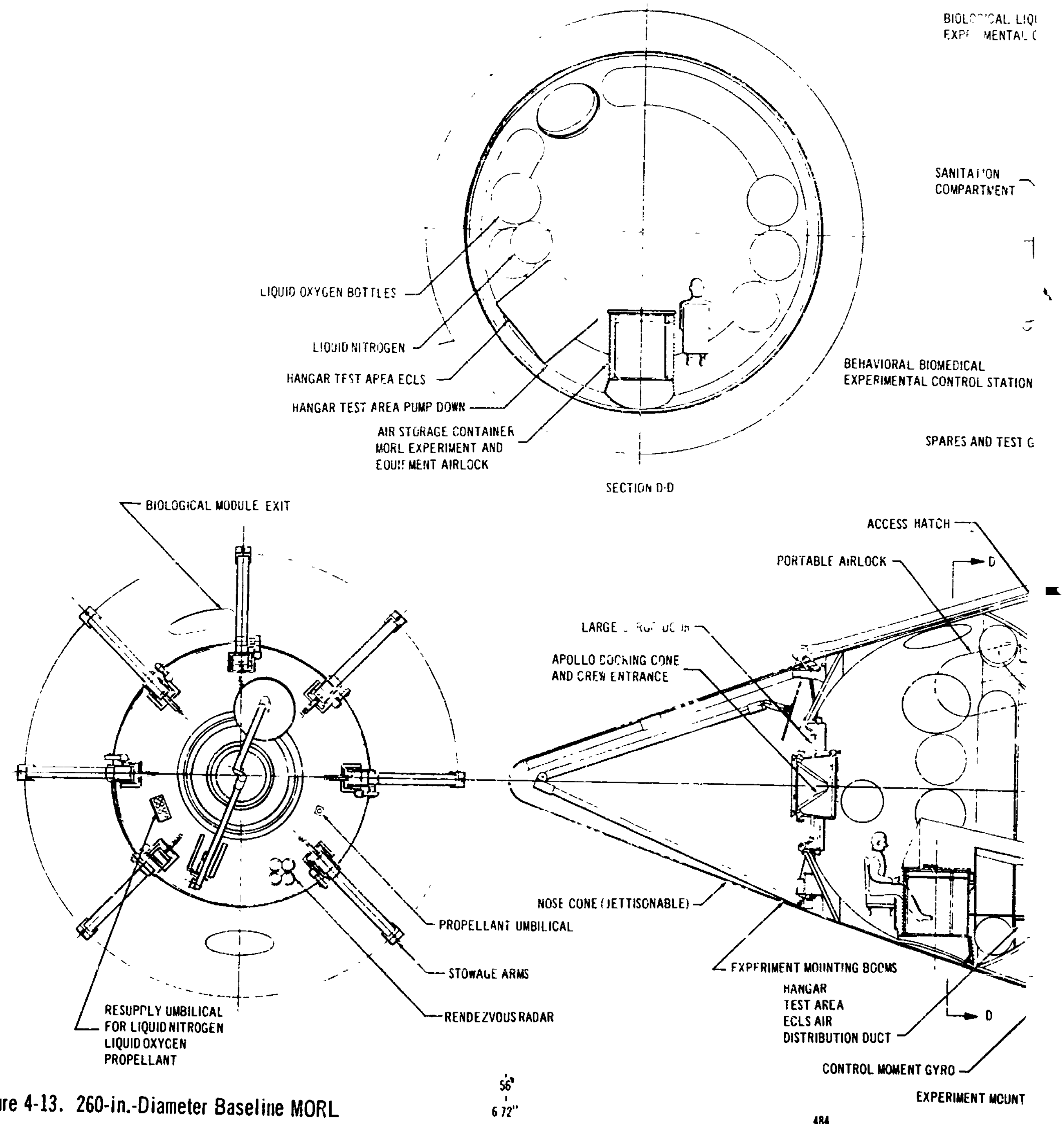
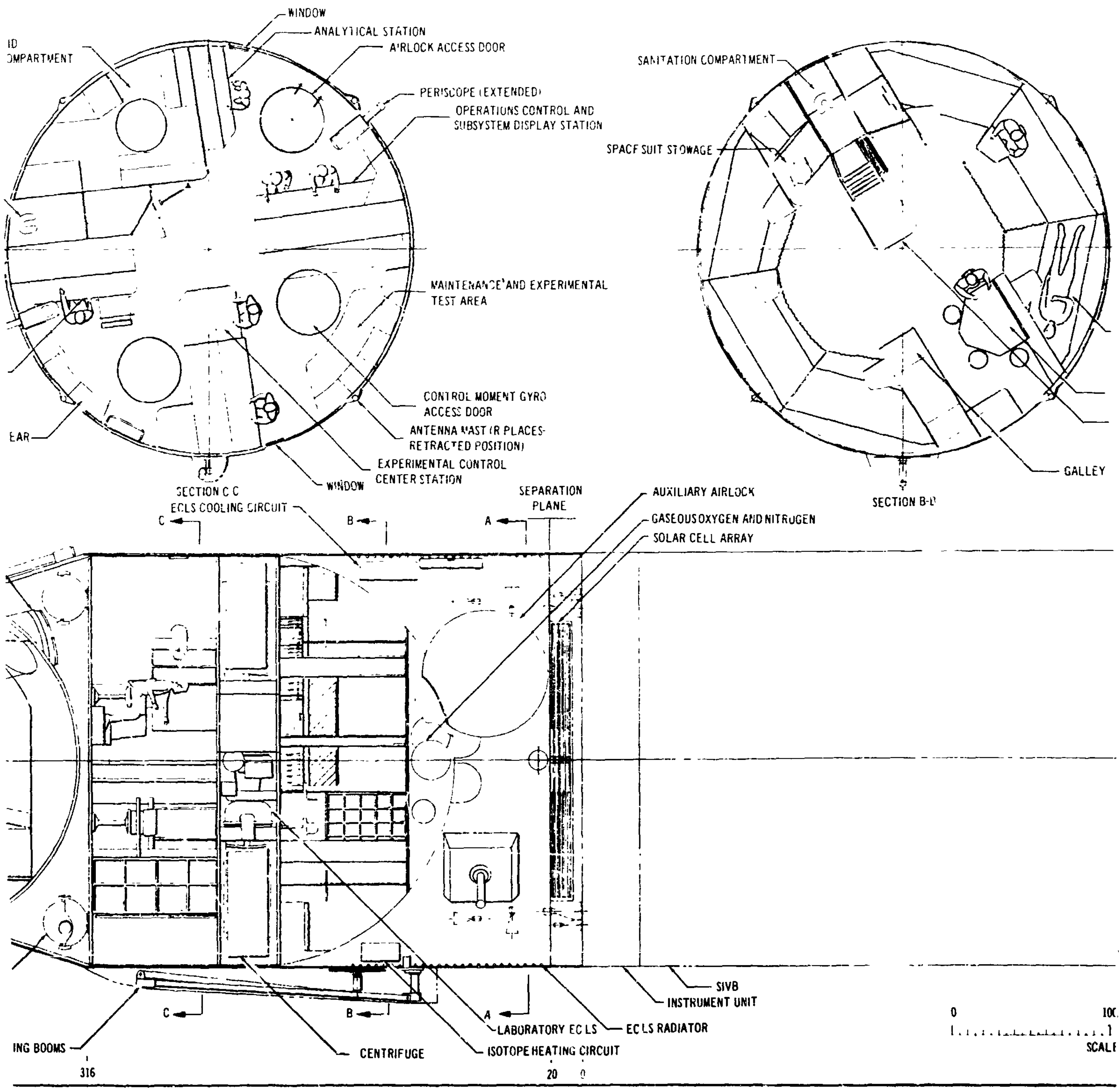


Figure 4-13. 260-in.-Diameter Baseline MORL



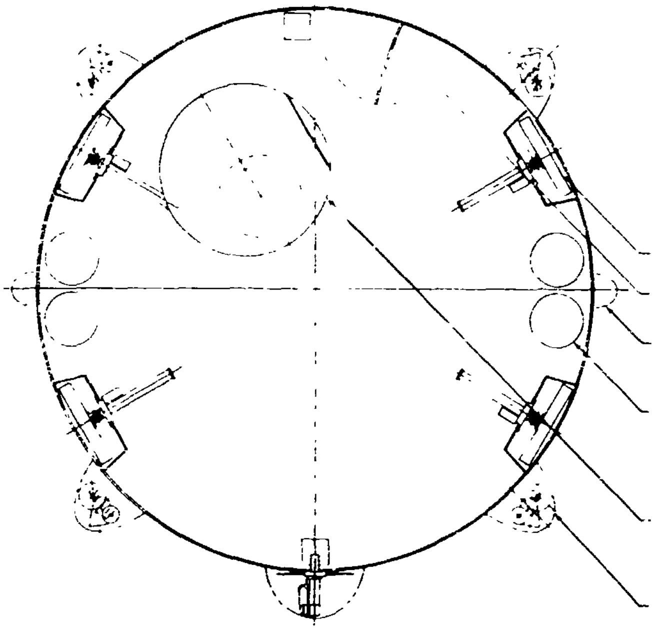
WINDOW
ANALYTICAL STATION
AIRLOCK ACCESS DOOR
PERISCOPE (EXTENDED)
OPERATIONS CONTROL AND SUBSYSTEM DISPLAY STATION
MAINTENANCE AND EXPERIMENTAL TEST AREA
CONTROL MOMENT GYRO ACCESS DOOR
ANTENNA MAST (R PLACES-RETRACTED POSITION)
EXPERIMENTAL CONTROL CENTER STATION
WINDOW
EAR
SECTION C C
SANITATION COMPARTMENT
SPACE SUIT STOWAGE
GALLEY
SECTION B-B
ECLS COOLING CIRCUIT
SEPARATION PLANE
AUXILIARY AIRLOCK
GASEOUS OXYGEN AND NITROGEN
SOLAR CELL ARRAY
SIVB
INSTRUMENT UNIT
LABORATORY ECLS
ECLS RADIATOR
ISOTOPE HEATING CIRCUIT
CENTRIFUGE
ING BOOMS
316
20
0
C
B
A
SCALE

2

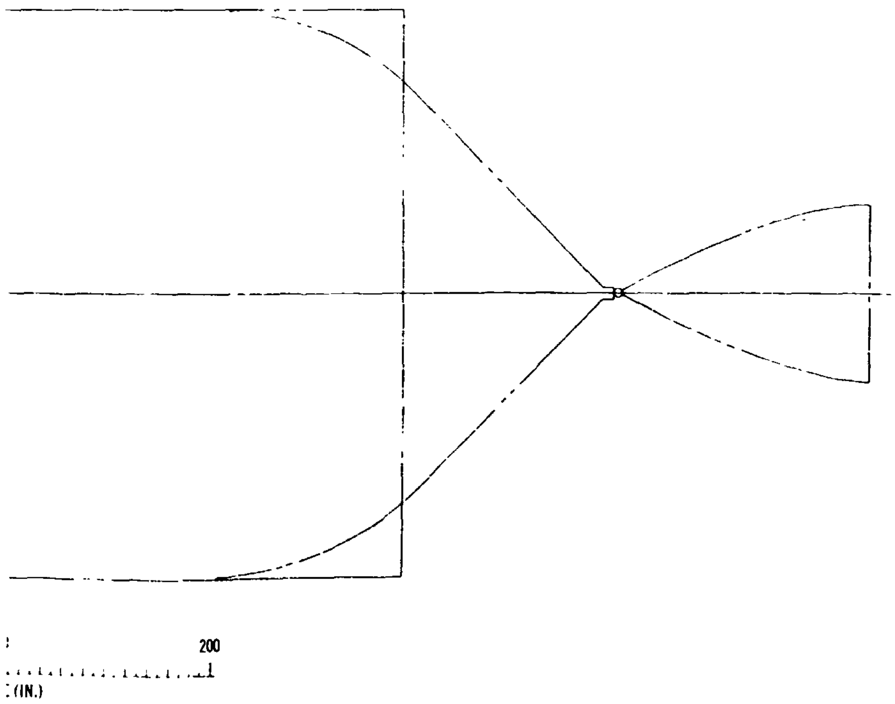
-CREW PRIVATE AREA

EATING AND RECREATION AREA

HATCH AND LADDER TO
LOWER TIER



SECTION A-A



3

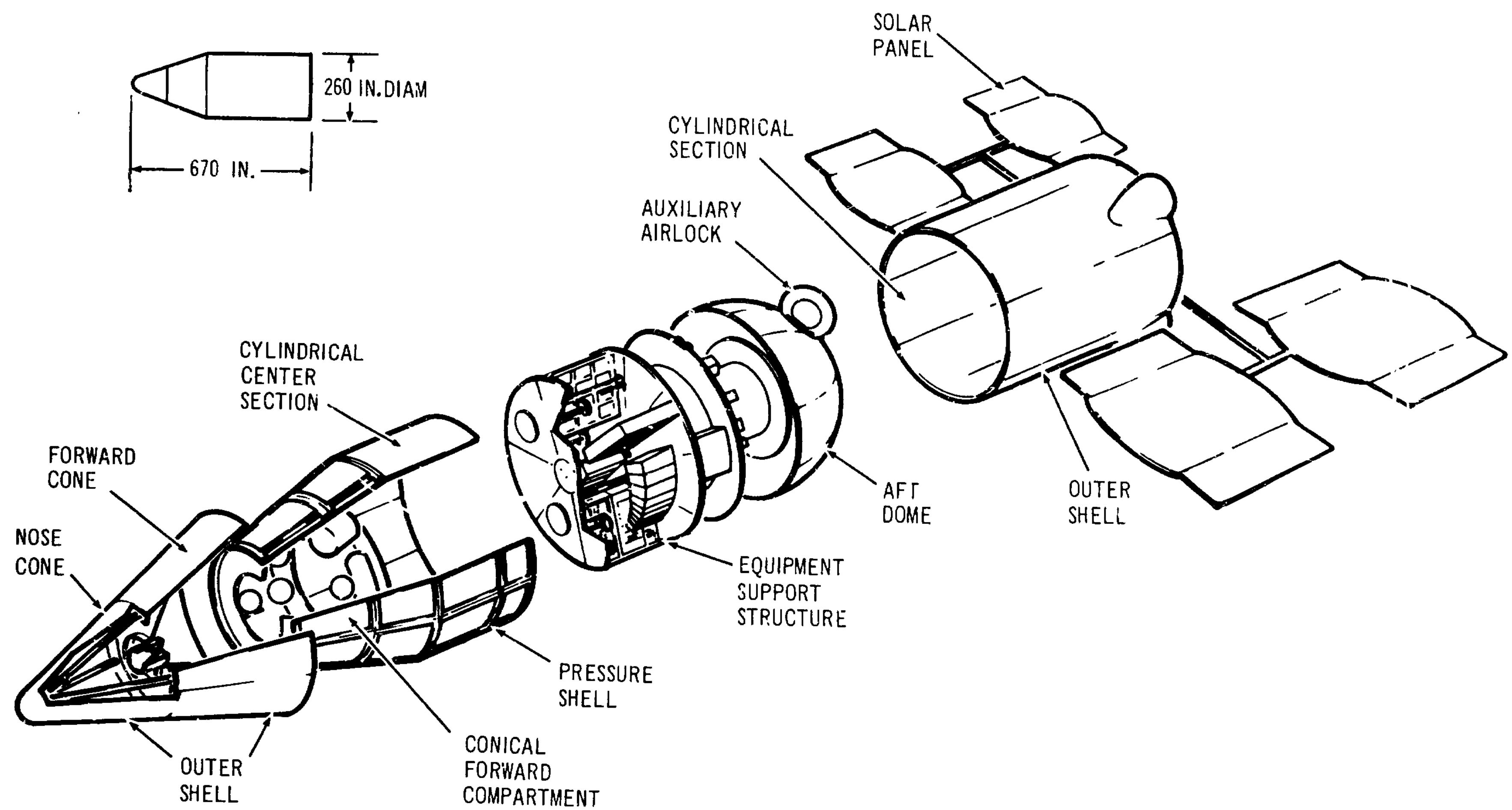


Figure 4-14. Major Assembly Breakdown

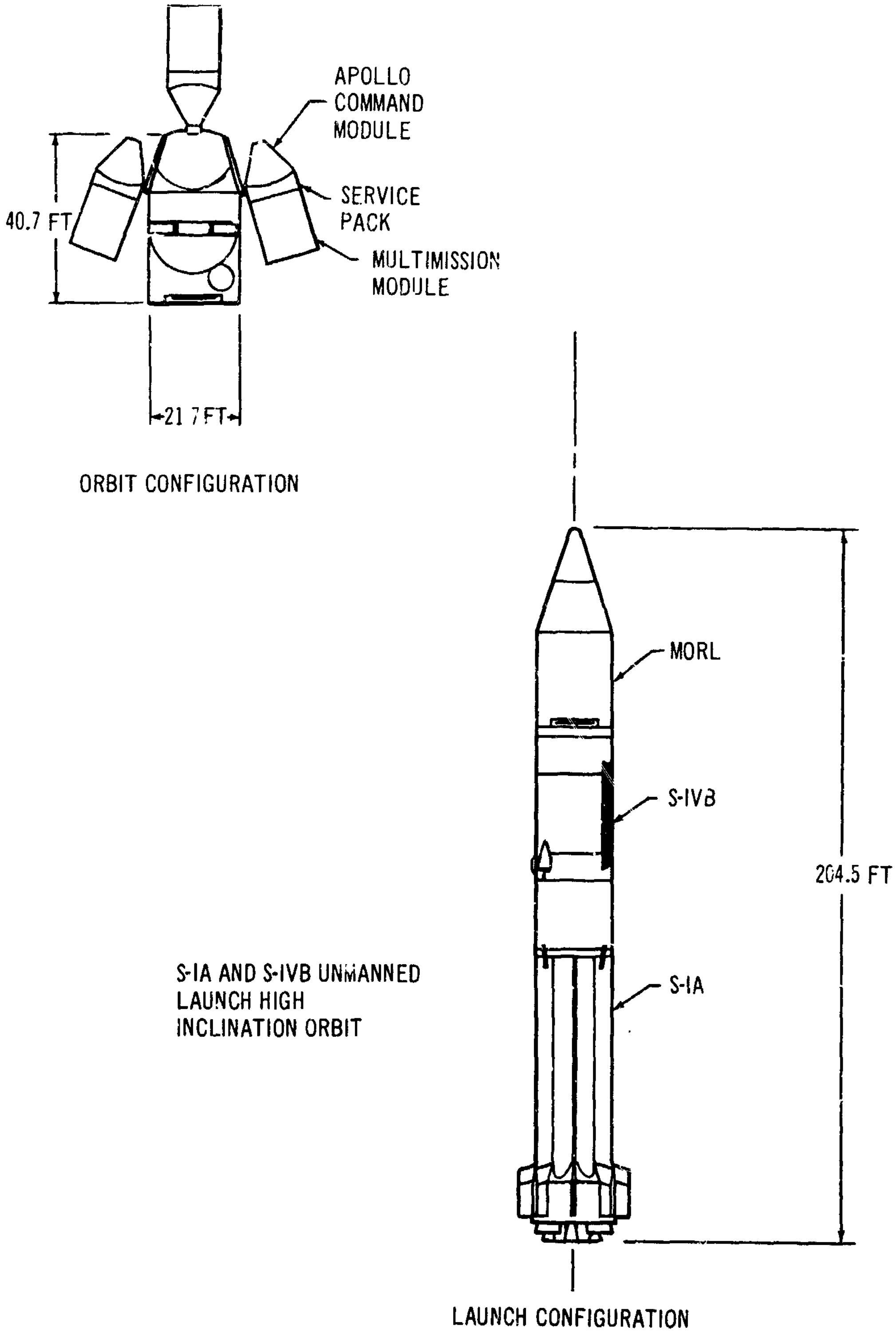


Figure 4-15. Laboratory and Launch Configuration – 50° Inclination

logistics vehicle is used to man the MORL. The Apollo must be fitted with a service pack to allow deorbit and Earth return of the Apollo. Three logistics craft are required for a MORL crew of nine men.

Polar Inclination, 200-nmi Orbit Mission

The launch and orbit configurations for the polar orbit mission are shown in Figure 4-16. On this mission the laboratory is launched unmanned by a Saturn V. The logistics system necessary for the 50° inclination orbit is used to man the MORL in polar orbit. The MORL orbit configuration may range from three to nine men, depending upon the mission requirements, without causing a change to the baseline MORL vehicle configuration.

Synchronous Orbit, 28° Inclination Mission

The launch and orbit configurations for the synchronous mission are shown in Figure 4-16. This mission also uses a Saturn V booster. It is launched unmanned and is manned by an Apollo/service module logistics vehicle. The Apollo service module is necessary to provide the thrust for deorbit and return of the crew from synchronous altitude. The MORL docking, cargo module stowage, and cargo handling systems must be revised to be compatible with the Apollo service module. The revisions will be restricted primarily to the hangar region, where the cargo module stowage arms must be changed to support the service module and the cargo pressure hatches must be revised. The method of delivering cargo to the MORL is similar to the baseline MORL system. With this system, changes to the MORL pressure hatches are minimized. The logistics system candidates are discussed in Section 4.4.

The internal configuration of the MORL is satisfactory for this mission. The increased altitude of a synchronous orbit will probably increase the size of individual sensors to achieve the same relative resolutions of a lower (200-nmi) altitude. This will require revisions to the sensor installation structure and thermal radiator locations.

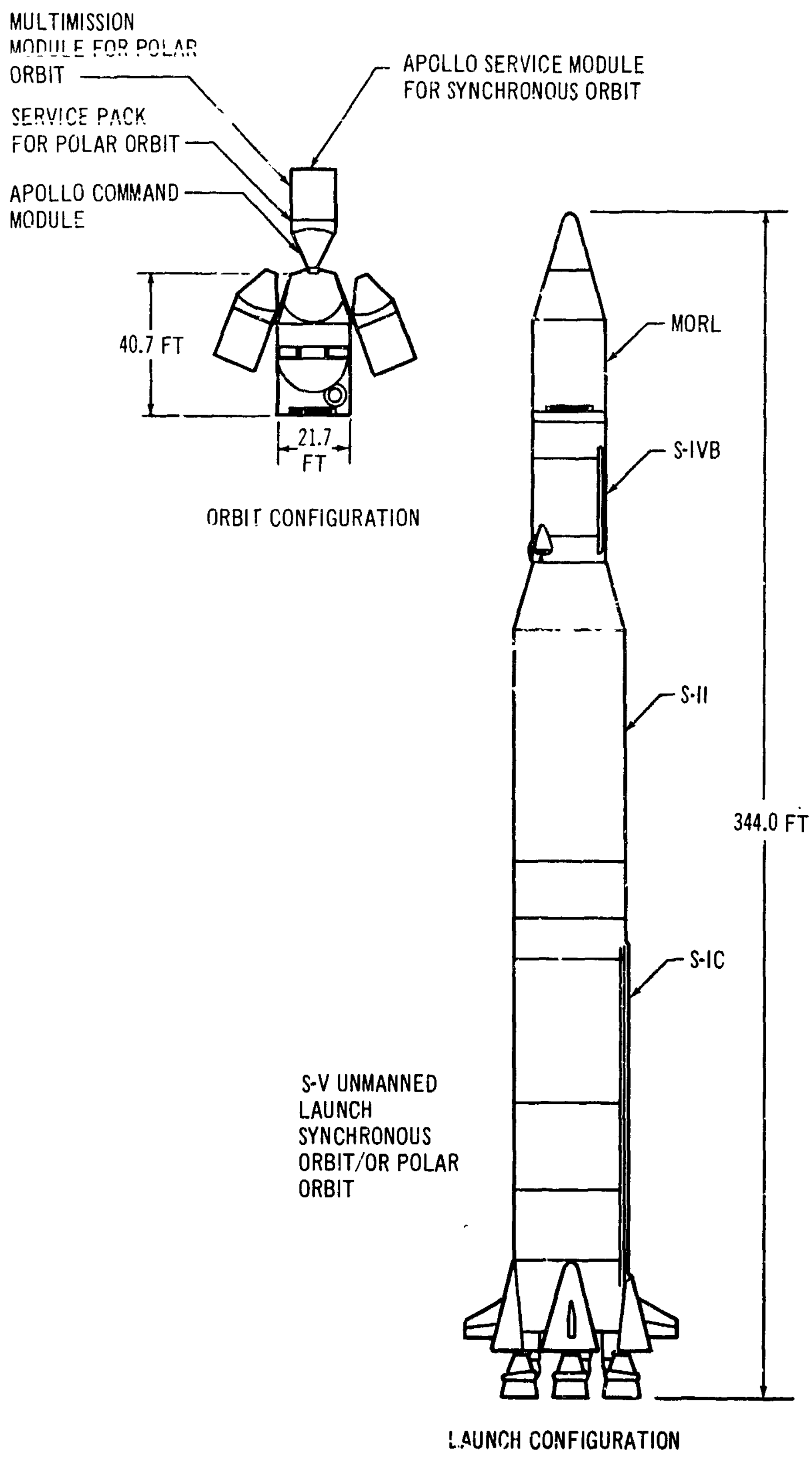
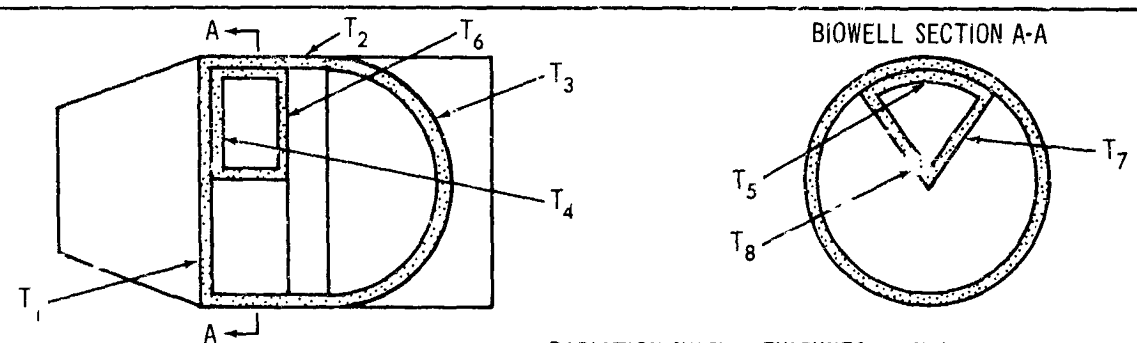


Figure 4-16. Laboratory and Launch Configuration – Polar and Synchronous Orbit

4.3.5.3 Structure Analysis

Radiation Shielding

The requirements for radiation shielding are fully developed in Section 6. The required shield thicknesses that must be added to the baseline structure vary according to the selected mission duration, source criteria considered, and many other parameters. The ranges of thicknesses of shield material required (polyethylene) are summarized in Figure 4-17. Also shown are the shield locations, including those for a potential biowell area. The shield thicknesses required for the two low altitude missions are moderate (less than 0.67 in.) while those for the synchronous mission are quite large (1.4 to greater than 10-in. thick).



ORBIT	WT (LB)	RADIATION SHIELD THICKNESS – IN.* T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8
50° 200 NMI	0 – 3,800	0 – 0.1	0 – 0.3	0.03 – 0.63	0 – 0.18	0 – 0.4	0 – 0.16	0	0
90° 200 NMI	0 – 2,500	0 – 0.17	0 – 0.27	0.03 – 0.57	0.18 – 0.32	0.5 – 0.67	0.16 – 0.32	0	0
28° 19,350 NMI (SYNCHRONOUS)	4,400 – 110,000	1.4 – 4	2.3 – 7	6.6 – 15	2.8 – 6	3.6 – 7	0	0	0

*MATERIAL – POLYETHELENE

Figure 4-17. Shield Thickness Ranges

Structural changes would be required in the launch load carrying members and the dome itself in order to support the large weights required. This thick material would also cause interference problems with sensors, RCS engines, electrical and other lines and fittings, and portals and optical elements. In addition, certain functions such as leak detection and radiator repair may be hindered. The problems incurred by adding large shield thicknesses appear to be formidable; however, when taken one at a time, they can probably be surmounted. Prior to this effort, however, the shielding philosophy must be better defined. Other means must be considered to reduce the large shield weights required for the resultant problems identified; then a more meaningful assessment of the structures design can be made.

Meteoroid Shielding

The baseline structure system will provide adequate meteoroid protection for the three missions. This protection is provided by the structural material surrounding the pressure vessel and by the shielding effects of the Earth itself. For a 1-year exposure, the probability of receiving zero punctures was determined to be 0.9949 for the two low altitude missions and 0.9921 for the synchronous mission.

The penetration flux defined by NASA was

$$\phi_p = 4 \times 10^{-10}\ t^{-3} \text{ penetrations/sq ft-day}$$

where t = effective thickness in in.

In Reference 5, this flux was determined for each major portion of the laboratory structure and then integrated over the entire structure; the average value of penetrations per year, ϵ, was found to be 5.14×10^{-3}.

The Poisson distribution was used to relate the probability of receiving r punctures to the average amount of punctures as follows:

$$P(r) = \frac{\epsilon^r e^{-\epsilon}}{r!}$$

where r = number of penetrations

ϵ = average number of penetrations per year

Evaluating this equation for $r = 0$ and $\epsilon = 5.14 \times 10^{-3}$ yields a probability of 0.9949 of receiving zero punctures in a 1-year exposure at the 200-nmi altitude.

For synchronous altitude the shielding of the Earth is reduced as shown in Figure 4-18. The Earth-shielding factor (SF) is defined as

$$SF = \frac{1 + \cos\theta}{2}$$

where θ is as shown in Figure 4-18

$$\theta = \sin^{-1} \frac{R}{R+h}$$

and R = Earth radius

h = satellite altitude

The resultant shielding factor is 0.65 for 200-nmi and 0.999 for 19,350-nmi (synchronous) altitude. The average amount of penetrations, ϵ, must be modified by this factor; thus, ϵ_s for a synchronous mission is 7.91×10^{-3} penetrations per year average. The probability of receiving zero punctures in 1 year on the synchronous mission is then, $P(o) = e^{-7.91 \times 10^{-3}} = 0.9921$. The baseline structure will provide adequate meteoroid shielding for all three missions.

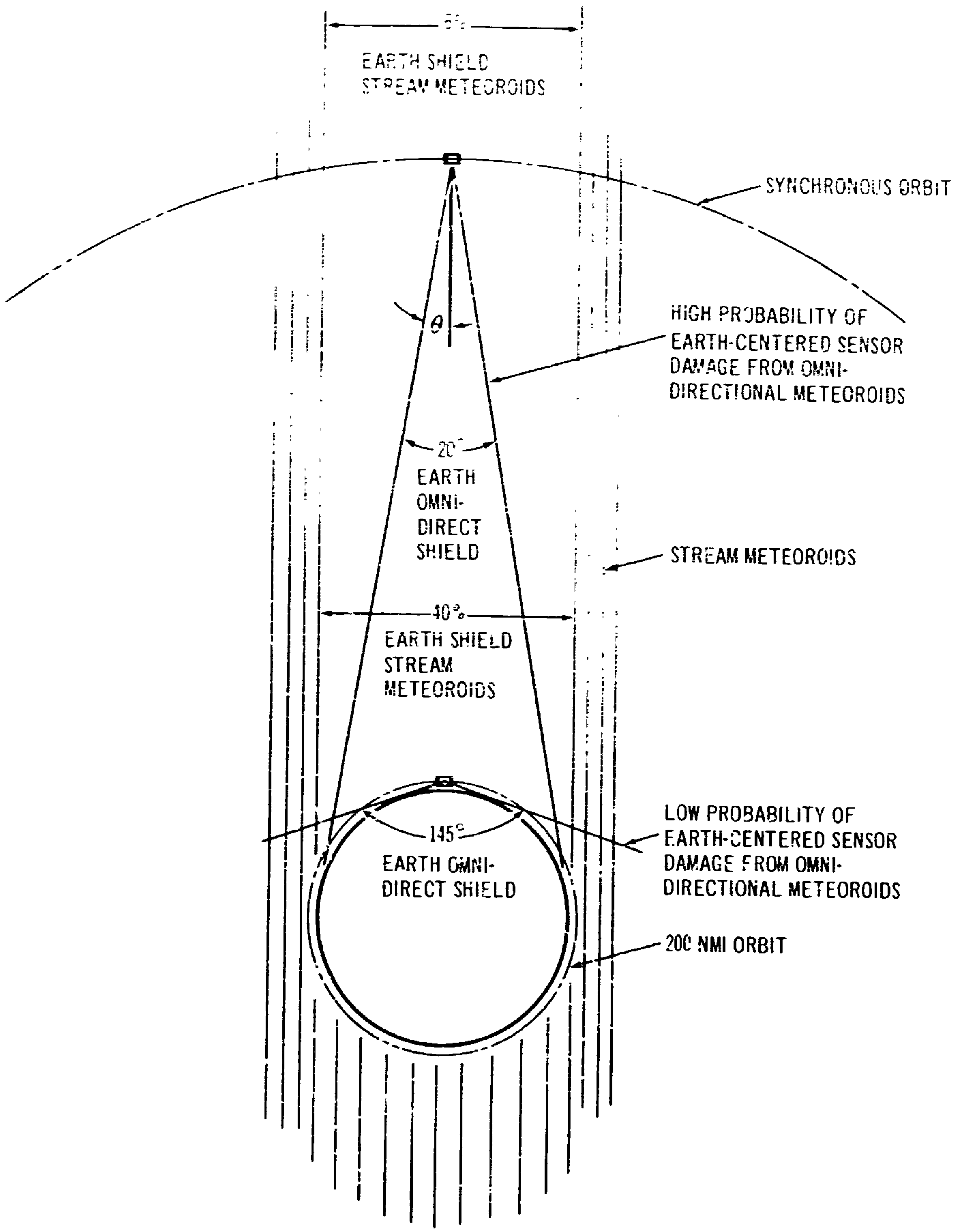


Figure 4-18. Earth Shielding from Stream and Omnidirectional Meteoroids

4.4 LOGISTICS SYSTEM

Several logistics system candidates were examined for each of the three MORL missions. The following are recommended:

1. 50° Inclination Mission--S-IB launched Apollo command module, service pack, and multimission module.
2. Polar Mission--S-V launched Apollo (Apollo command module, service pack, and multimission module).
3. Synchronous Mission--S-V launched Modified Apollo (Apollo command and service module, and multimission module).

All were chosen for their superior cargo-carrying capability. Table 4-18 presents a summary comparison of those systems examined.

4.4.1 Logistics System Requirements

The mission requirements that must be satisfied by the logistics system are (1) to support the six-man MORL on a 90-day resupply schedule (2) the crew must be rotated to ensure an average tour of duty of 180 days, and (3) the cargo capability must be about 10,000 lb/flight. This was determined by examining the experiment requirements dictated by the Experiment Plan plus the other consumables needed, such as crew requirements, RCS/SCS propellant, spares and so forth. The experiment weight requirements for the 50° mission, obtained directly from the Experiment Plan, are shown in Figure 4-19. A large initial block of experiment weight must be lifted, about 15,000 lb during the 1st month, and then a very modest amount monthly thereafter. The monthly consumable requirements for all three missions are shown in Figure 4-20. The requirement for the 50° inclination mission is 1,850 lb/month.

The manning concept retained from Phase IIa requires that three 3-man Apollo flights be made in the first 45-day period. The first launch is to activate and check out the laboratory; the next two, about 45 days later, are to rotate the checkout crew and fully man the laboratory. Crew rotation and resupply follows at regular 90-day intervals. The total logistics weight required on these flights, including the requirements for 150-days' house-keeping supplies, approximately 1,500 lb of initial spares, and the

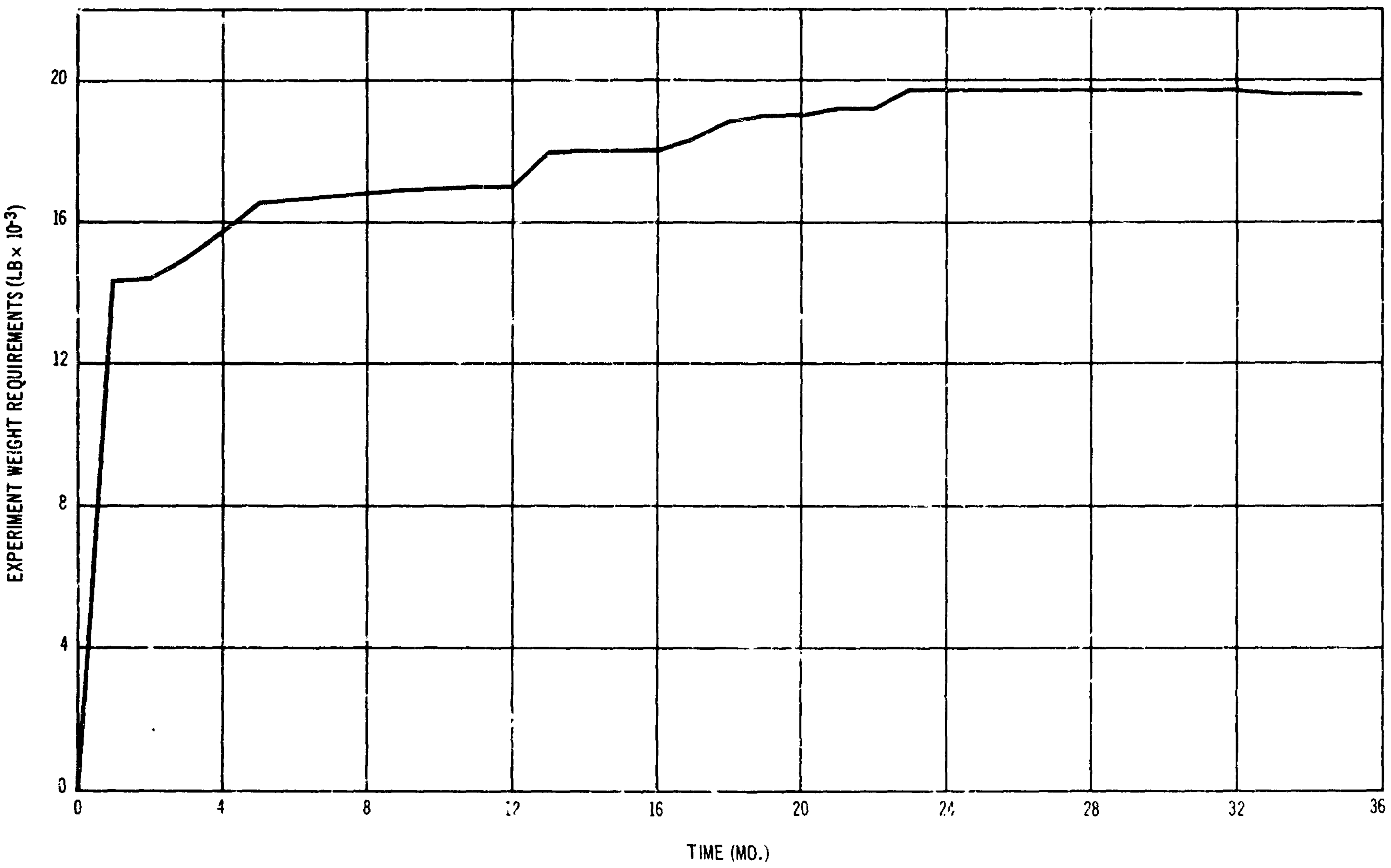


Figure 4-19. Experiment Program Weight Requirements

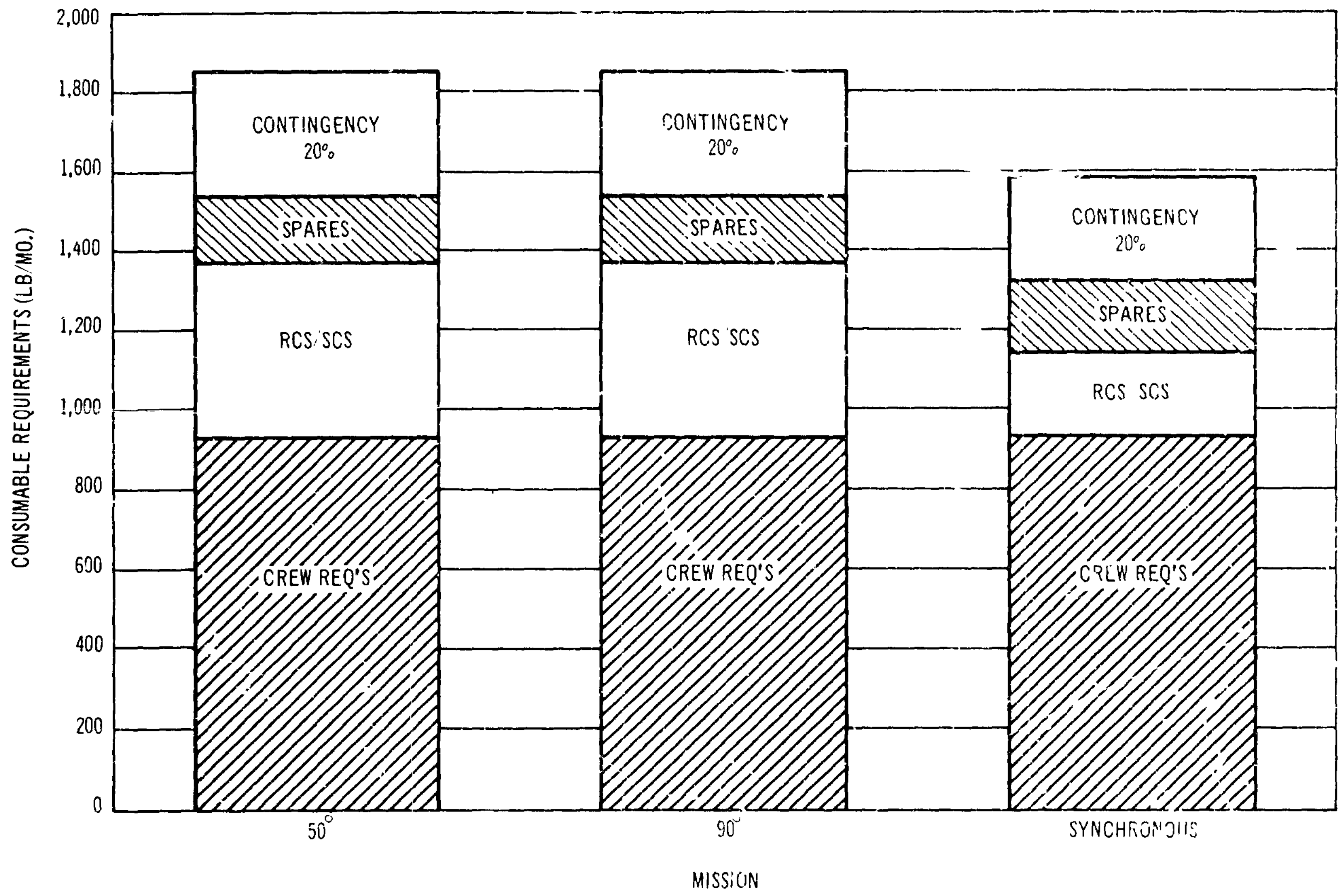


Figure 4-20. Monthly Consumable Requirements

Table 4-18

LOGISTICS SYSTEMS SUMMARY

Mission	Logistics Spacecraft	Launch Vehicle	Launch Azimuth (o)	Spacecraft Empty Wt (lb)	Cargo Capability (lb)	Launches Required/Year Re-supply	Launches Required/Year Crew Ro-tation	Comments
Baseline 200 nmi 50° inclination	AES(CSM)	S-IB	44.5	20,100 to 18,800	7,100 to 8,100	5	4	Higher-cargo capability results mainly from deletion of 21,900 SPS engine
	Apollo CM SP/MMM	S-IB	44.5	21,300	10,500	4	4	
Polar 200 nmi 90° inclination	Apollo CM SP/MMM	S-IB	146	20,500	1,600	-	4	With WTR launch, cargo capability = 6,100 lb
	Apollo CM SP/MMM	S-IC + S-II	146	23,400	131,900 20,000*	2	4	*Cannot utilize full payload capability. Assumes 20,000 lb maximum cargo carried in multimission module
	Apollo CSM/MMM	S-IC + S-II	146	31,100	121,500 20,000*	2	4	
	Apollo CSM/MMM	S-V	146	30,400	133,600 20,000*	2	4	
	Apollo CSM/MMM	S-V	44.5	26,200 to 24,200	3,000 or 5,000	-	4	Higher cargo capability results from deletion of 21.9K SPS engine
	Apollo CM SP/MMM	S-V	44.5	21,700	10,200	4	4	
Synchronous 19,350 nmi 28.3 inclination 98°W. long.	Apollo CSM/MMM	S-V	90	38,100	19,000	2	4	

experimental gear required in the first 90-days is 26,000 lb. Less than 9,000 lb/flight will be required for the 50° inclination mission.

The cargo requirements for the remainder of the flights for the 50° inclination mission are less (about 6,000 lb), but 10,000 lb will be used as the design number to allow for growth. The experiment cargo requirements for the polar and synchronous missions are not so self-evident since experiment requirements for these missions have not been developed. The consumable requirements for these latter missions are shown in Figure 4-20. They are 1,850 lb/month and 1,580 lb/month for the polar and synchronous missions, respectively. In the absence of the experiment weight required for these two missions, the same requirement as determined for the 50° inclination mission will be used, namely 10,000 lb/flight.

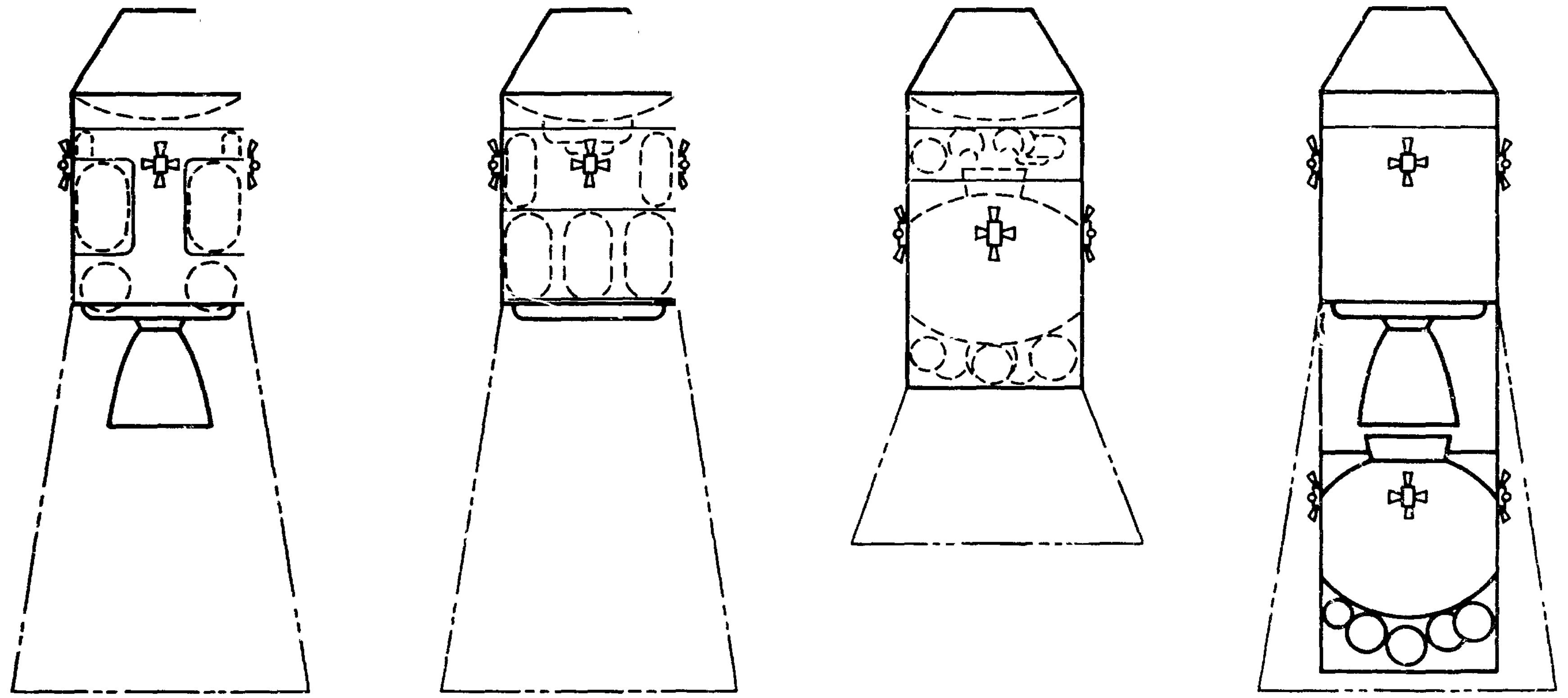
4.4.2 Logistics System Candidates

As shown in Figure 4-21, four basic configurations were evolved during the study:

1. AES-Derived Logistics Vehicle--Apollo Extension Systems command and service modules modified for the logistics mission.
2. Apollo CSM-Derived Logistics Vehicle--Block II Apollo command and service modules utilizing Modified Apollo Logistics Spacecraft (MODAP) modifications, with service propulsion system removed.
3. Baseline Apollo Logistics Vehicle--MORL Phase IIa logistics vehicle (Apollo command module, service pack, and multimission module) modified as required for the new laboratory missions.
4. Modified Apollo Logistics Vehicle--Block II Apollo command and service modules (with minimal modifications for the logistics mission) plus a MORL multimission module suspended from the aft end of the service module.

The particular combinations of logistics vehicle, launch vehicle, and launch azimuth studied for each mission are shown in Table 4-19.

As indicated, the synchronous orbit logistics vehicle utilizes the Saturn V launch vehicle and the Apollo service module. The latter is required to deorbit the command module. Therefore, cargo must be carried in a separate



	AES DERIVED	APOLLO CSM (WITHOUT SPS)	APOLLO CM PLUS SP AND MMM (BASELINE)	APOLLO CSM PLUS LEM ADAPTER WITH MMM
CARGO CAPABILITY	7,100 LB	8,100 LB	10,500 LB	19,000 LB
LAUNCH VEHICLE	S-IB	S-IB	SI-B	S-V
LAUNCH AZIMUTH	44.5°	44.5°	44.5°	90°
LAUNCH SITE	ETR	ETR	ETR	ETR

Figure 4-21. Logistics Spacecraft Configurations

Table 4-19

LOGISTIC SYSTEM ALTERNATIVES

LEGEND:
- X Configuration Studied
- \+ Tentative Prime Candidate

Mission	Launch Vehicle	Launch Azimuth	Launch Site	Logistic Vehicle Configuration: AES CSM	Apollo CSM	Apollo CM, SP, MMM (baseline)	Apollo CSM, MMM
50° Inclination Orbit	S-1B	44.5°	ETR	X	X	+	
Polar Orbit	S-1B	146.0°	ETR			X	
		182.0°	WTR			X	
	S-1C/S-II	146.0°	ETR			X	X
	S-V	146.0°	ETR				X*
		44.5°	ETR			+	X
Synchronous Orbit	S-V	90.0°	ETR				+

*Configuration with and without SM main propulsion system studied.

cargo module, such as the multimission module (MMM) configured in Phase IIa. The MMM is, in this case, housed within the LEM fairing. Rendezvous is accomplished by use of the MMM RCS and the Apollo SM RCS.

The polar-orbit logistics vehicle could be identical to the synchronous-orbit logistics vehicle. An alternative approach would utilize the service pack (SP) evolved during Phase IIa as the functional equivalent of the service module. In this case, the MMM would be located between the SP and a fairing on the Saturn launch vehicle.

Additional candidates for the polar logistics mission are afforded by the introduction of two-stage Saturn V's into the study. However, because no other missions could be identified for these configurations, they are not favored at this time. It is interesting to note that the MORL baseline logistics system (the Saturn IB-launched Apollo CM/SP/MMM spacecraft) offers adequate capability to serve as a crew-carrier into polar orbit. It may be advantageous to use it in combination with a Saturn V launched logistics vehicle to reduce the usage of the latter.

As a first step in the selection of a logistics system, several logistics vehicle concepts were configured for the three laboratory missions. The main limitations on concept selection were as follows:

1. Only Saturn IB, S-IC/S-II, and Saturn V launch vehicles were considered.
2. Only combined ferry/resupply logistics missions were considered. (Potential alternatives could have been separate systems for laboratory consumable resupply and for ferrying crew members, and combined ferry/resupply systems supplemented by pure ferry systems.)
3. Use of Apollo and Apollo-derivative AES systems was emphasized.
4. Modifications to Apollo systems were held to a minimum commensurate with the mission.
5. Only three-man Apollo command modules were considered.
6. In order to provide return capability at all times for the entire crew, two Apollo command modules must always be present on the laboratory and stowed in a manner so as to leave the hanger/test area clear for other uses.

4.4.3 The 50° Inclination Mission

4.4.3.1 Mission Profile Effects

The mission profile requires that the logistics vehicle provide all impulses after the Saturn IB injects the spacecraft into the 87-nmi x 200-nmi transfer orbit. Thus, the logistics vehicle propulsion systems must furnish orbit circularization, rendezvous, and docking velocity.

The exact velocity required for the plane rotation maneuver during rendezvous was described in Section 4.2 as a function of the launch window. For two of the specific logistics vehicles configured, the effect of prolonging the launch window on cargo capability is graphically demonstrated by Figure 4-22. From knowledge of the Saturn IB launch operations capability and the above data, the maximum launch window was set at 5 min.

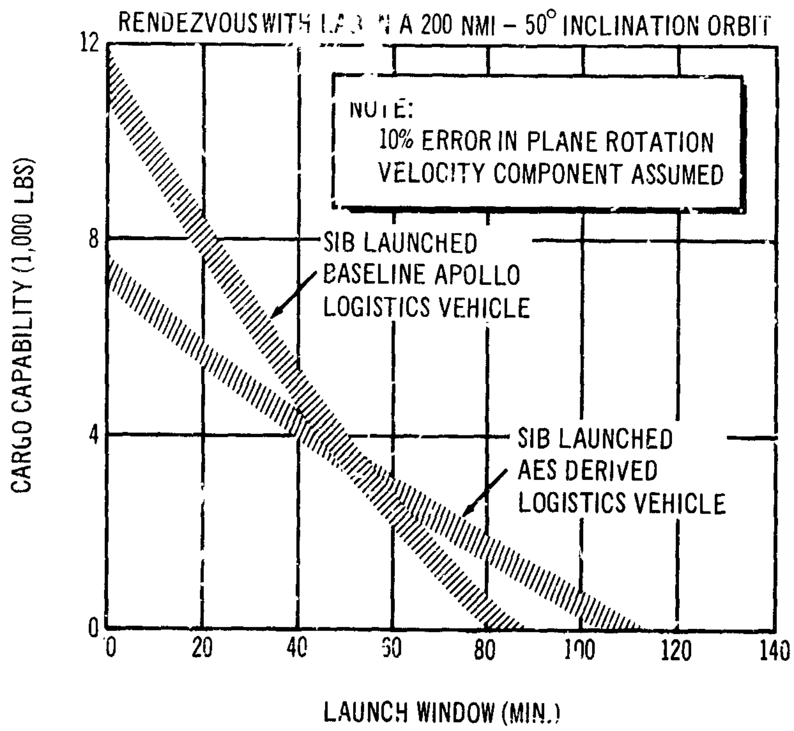


Figure 4-22. Cargo Penalty as a Function of Launch Window

As pointed out in Section 4.2, rendezvous may take almost 3 days, instead of the previous Phase IIa guarantee of less than 24 hours. This imposes new requirements for the logistics vehicle's electrical power and environmental control/life support systems.

The command module must be given roughly a 550-fps deorbit impulse to return the crew to Earth. This impulse will be imparted by either the service module main propulsion unit or by a solid propellant retropack. Any unmanned modules must be furnished 190-fps deorbit impulse for destructive re-entry.

4.4.3.2 S-IB/AES-Derived Logistics Vehicle

This concept makes maximum usage of the components and subsystems of the Apollo Extension-Systems (also referred to as Extended Apollo Systems or Apollo X) as defined by Reference 6, and utilizes these AES subsystems with an absolute minimum of modification. Therefore, some of the subsystems retained as defined for the AES 3-man, 45-day Earth-orbit mission have more capacity and/or are over-designed for the 3-man, 3-day logistics mission. For example, the life support system is designed for 135 man-days of orbital operations with a two-gas (O_2, N_2) atmosphere. Plumbing and tankage changes in the service module alone result in more than 300 lb of changes over the Block II system. The logistics vehicle requires only nine man-days of a one-gas atmosphere, a requirement much closer to the Block II system than to the AES.

This configuration retains the 21,900-lb thrust service propulsion system (SPS) for macrorendezvous and deorbit impulse. The SM 100-lb thrust RCS engines provide microrendezvous and docking impulse.

A potential configuration is shown in Figure 4-23. It utilizes a three-man Apollo Block II command and service module (CSM) modified for the AES mission and then remodified for the logistics mission. A LEM adapter is used as a fairing from the S-IVB to the service module. The fairing clamshells open and the logistics vehicle thrusts away from it and the expended S-IVB at the first rendezvous maneuver.

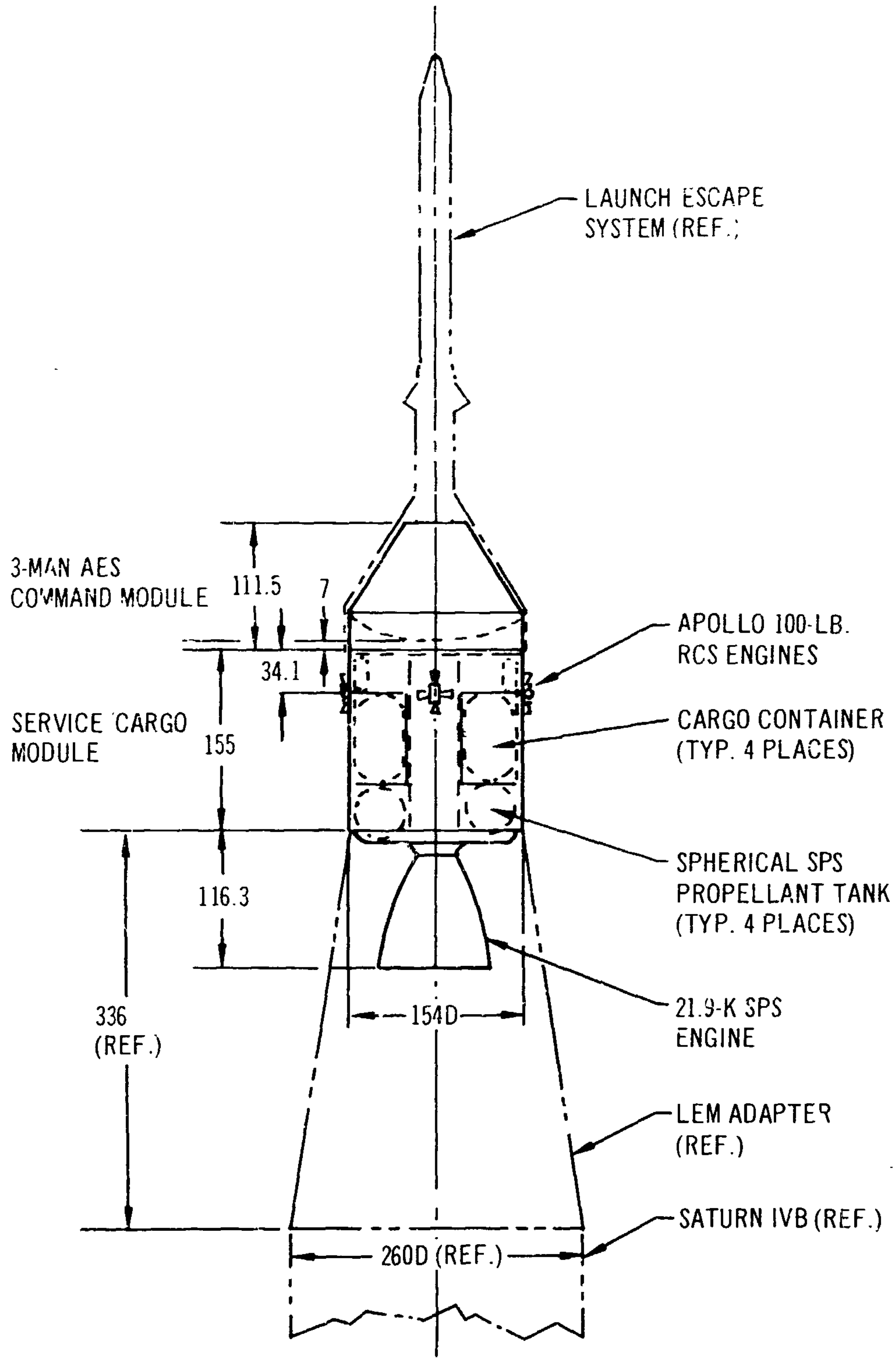


Figure 4-23. Saturn IB/AES-Derived Logistics Vehicle

The major changes in the Block II Apollo for conversion to a three-man, 45-day Earth-orbiting AES space station are given below (Reference 6. Volume 2, page 6):

1. Add a two-gas atmosphere and trace contaminant control.
2. Add 2 fuel cells and 45-day reactant storage in the service module.
3. Add environmental control system and 135 man-day cryogenic storage in the service module.
4. Add two C-band transponders to the communications system for ground tracking.
5. Replace the service module main propulsion tanks with small tanks.
6. Add redundancies to meet 45-day Earth mission reliability goals.

A logistics version of the AES can make do with most of these modifications even though they may be redundant or excessive for the mission. One modification that cannot be used is the addition of fuel cells since the fuel-cell system must be replaced by batteries. Cryogenic reactant storage for up to 6-months staytime in space appears impractical. Also, emergency evacuation of MORL requires a power source with a short reaction time, which is difficult to achieve with fuel cells.

Several additional modifications are necessary to adapt the AES to the logistics mission. The modifications shown in Reference 9, (pages 101 and 102) appear to be the minimum required to adapt the AES command module to the MORL logistics mission.

With this concept, the service module must be modified to carry solid and liquid cargo. Similar modifications were thoroughly examined and reported in Reference 7. MODAP-type modifications that must be made to the service module include the following (Reference 17, page 58):

1. Structure--Add cargo doors, liquid storage bottles, and web reinforcements.
2. Electric power--Replace Apollo fuel cells with batteries for three-day ascent and two-day descent mission phases (orbital storage power furnished by MORL). Requires minor modification to power distribution system.

3. Environmental control life support--Replace water-glycol circuit with water tanks and add oxygen supply tanks (water and oxygen previously furnished by fuel-cell system).
4. Propulsion--Replace service module main propulsion tanks with smaller tanks and modi. plumbing and pressurization equipment accordingly.
5. Instrumentation--Remove LEM monitoring instrumentation.

The MODAP solid-cargo transfer techniques that must be used with a modified service module are not compatible with MORL baseline design. Special handling arms and cargo hatches will have to be incorporated into the laboratory de. n. In addition, solid cargo must be packaged in special, hermetically sealed transfer containers because the cargo will be exposed to space during the transfer process. This results in a net weight loss of 21% of the available cargo capability (Reference 7, page 84). Approximately 730 cu ft of space is available for cargo storage in four of the six service module sectors.

Apollo Block II weights as reported in Reference 8 (pages 171 to 181) are used as the base for all logistics concept extrapolations. Based on this information, the vehicle configured above can carry 7,080 lb of useful cargo on the 50° inclination mission.

4.4.3.3 S-IB/Apollo CSM-Derived Logistics Vehicle

The approach taken for this concept is to utilize Block II (Lunar) Apollo command and service module components and subsystems with as little modification as seems reasonable. The main configural difference between this and the AES-derived concept is that the 21,900 thrust SPS engine is removed completely, leaving more volume and weight available for cargo. Rendezvous impulse is provided by existing SM RCS engines with enlarged tankage. CM deorbit impulse is provided by a solid-propellant retropackage.

A potential configuration, shown in Figure 4-24, is made up of a minimally modified Block II Apollo three-man command module, a solid-propellant retropack, an extensively modified service module, and a LEM adapter. The deorbit retropack is the MODAP recommended system (Reference 7, page 62).

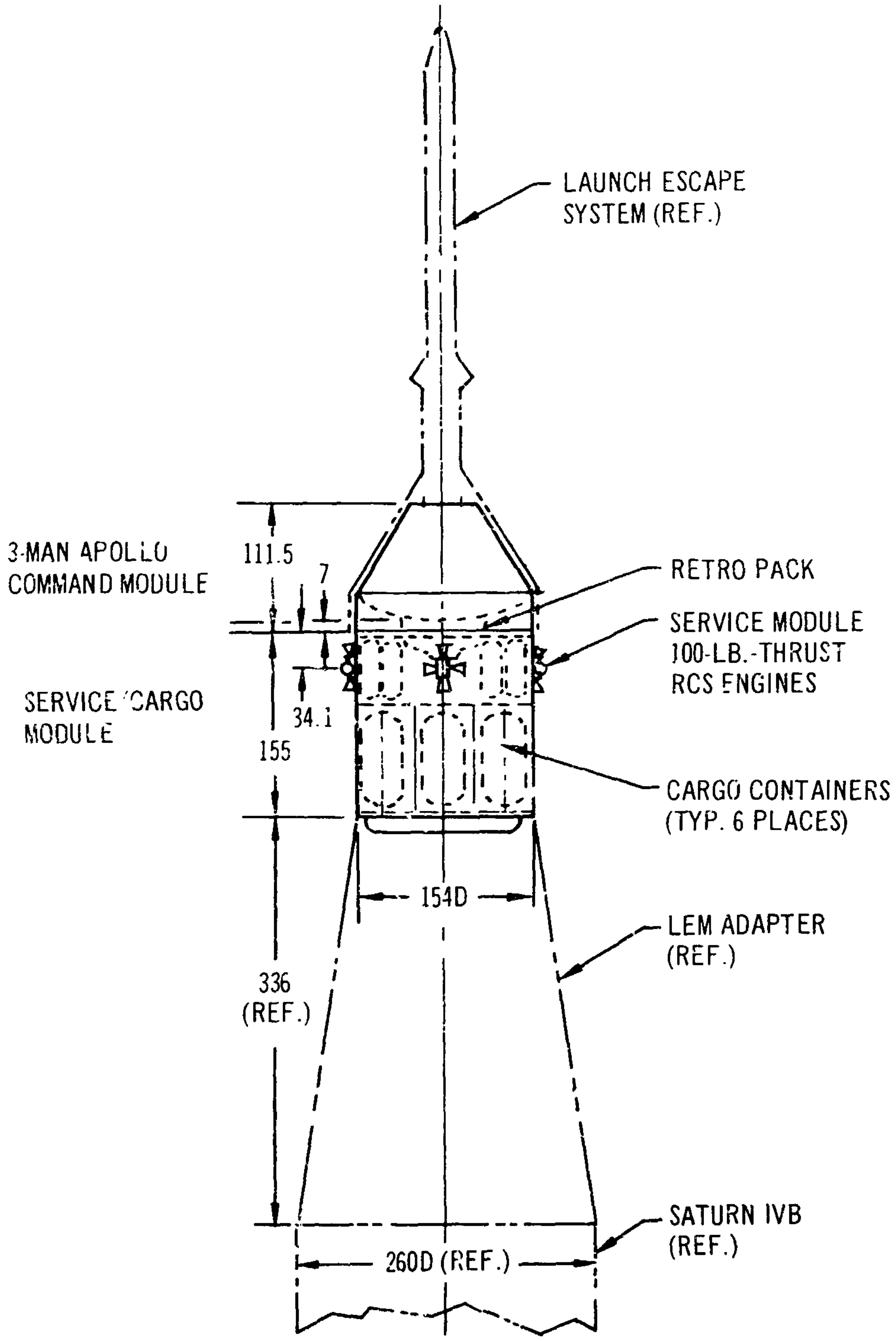


Figure 4-24. Saturn IB/Apollo CSM-Derived Logistics Vehicle

The service module internal configuration is radically modified by (1) removal of the whole service propulsion system, (2) changing the electrical power source from fuel cells to batteries, (3) enlargement of reaction control tankage (by replacing existing units with dual sets of LEM RCS tanks), and (4) adding cargo provisions. With these modifications, more than 1,300 cu ft of the 1,670 cu ft internal volume is available for cargo.

The LEM adapter is again utilized as a fairing from the S-IVB to the service module and is separated from the logistics vehicle with the expended S-IVB stage.

The command module must have essentially the same modifications as were required for the baseline MORL logistics mission (Reference 9, pages 101 and 102). The only difference is that the electrical power and EC/LS systems must be sized for the slightly longer ascent and descent phases.

The service module must be modified for the logistics mission as follows:

1. Structure--Add cargo doors, liquid storage bottles, and appropriate web reinforcements. Modify forward bulkhead to accommodate CM retropack.
2. Electrical Power--Replace Apollo fuel cells with batteries for ascent and descent phases.
3. Environmental Control/Life Support--Removal of fuel cell system requires addition of water and oxygen supply.
4. Propulsion--Remove service propulsion system. Replace existing RCS tanks with multiple sets of LEM RCS tanks. Modify plumbing and pressurization equipment.
5. Subsystems--Modified as applicable to meet the requirement for 6-month orbital storage.

Minor modifications are also made to the electrical power distribution and instrumentation systems. MODAP cargo transfer techniques would probably be used with this concept, thus requiring special cargo containers, laboratory cargo handling arms, and hatches with their associated penalties.

These modifications allow the Apollo CSM-derived configuration to carry 8,140 lb of useful cargo for this mission.

An alternate approach might be considered. Since the whole aft end of the service module is available for cargo, it is conceivable that it could be made into a pressurizable compartment with a docking hatch centrally located on the aft bulkhead. The service/cargo module could then be docked to the MORL hangar test area and solid cargo transferred manually in a shirt-sleeve environment.

4.4.3.4 S-IB/Baseline Apollo Logistics Vehicle

This concept utilizes the MORL Phase IIa baseline logistics vehicle (Reference 9) essentially unmodified. This configuration is shown in Figure 4-25 and is made up of the following:

1. A modified Apollo Block II three-man command module.
2. A service pack to provide on orbit propulsion, EC/LS, power and SCS function to the command module.
3. A multimission module for either cargo, experiments, laboratory modification, or a laboratory excursion propulsion system. A new fairing from the S-IVB stage to the multimission module is utilized in place of the LEM adapter.

The only variance from Phase IIa baseline subsystem design results from the ascent phase of the logistics mission tripling (approximately 3 days to rendezvous instead of less than 24 hours). This requires enlarging the service pack EC/LS oxygen and water supplies and adding EPS batteries. This configuration can carry 10,480 lb of useful cargo to the laboratory in the 50° inclination orbit.

4.4.3.5 Proposed Vehicle

The baseline Apollo (command module, service pack, multimission module) is the logistics vehicle recommended for the 50° inclination mission on the basis of the following:

1. Cargo capability (10,500 lb versus 8,100 lb for the Apollo CSM-derived vehicle).
2. Ease of cargo handling.
3. Mission flexibility.

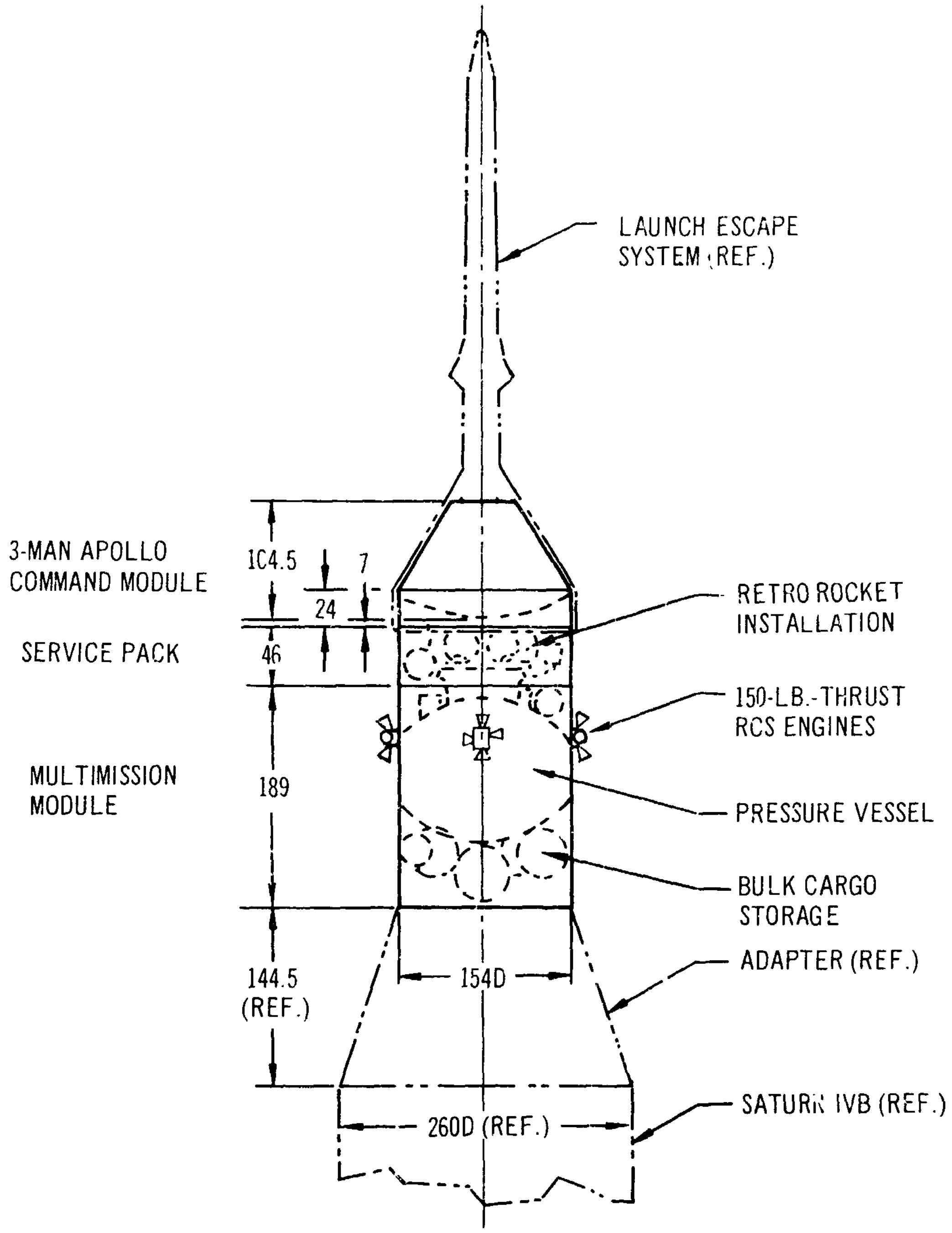


Figure 4-25. Saturn IB/Baseline Apollo Logistics Vehicle

The AES-derived logistics vehicle is less desirable than the Block II Apollo CSM-derived vehicle because the AES mission requires changes to the Block II Apollo subsystems that degrade its logistics capability.

4.4.4 The Polar Mission

4.4.4.1 Mission Profile Effects

Polar mission profiles are described in some detail in Section 4.2. Three launch vehicles are being considered: (1) the Saturn IB, (2) the two-stage Saturn V or S-IC/S-II, and (3) the three-stage Saturn V. Three launch azimuths are also under consideration: 44.5° from ETR, 146° from ETR, and 182° from WTR.

With each combination of launch azimuth and launch vehicle the rendezvous requirements are essentially the same. After injection into an 87-nmi x 200-nmi transfer orbit, the logistics vehicle propulsion system must furnish orbit circularization, rendezvous, and docking velocity. Total rendezvous requirements are again a function of launch window because of its effect on plane rotation maneuvers. For three of the logistics vehicles mentioned in the following paragraphs, the specific effect of prolonging the launch window on cargo capability is shown in Figure 4-26. A 5-min. launch window for the Saturn IB, S-IC/S-II, and Saturn V was again picked as a design point. Other polar mission requirements are assumed to be identical to the 50° inclination mission requirement. Particular combinations of launch profiles, launch vehicles, and spacecraft will now be considered individually. First, those combinations using the baseline logistics spacecraft (command module, service pack, and multimission module) will be discussed; this will be followed by a discussion of configurations that use the command module, service module, and a multimission module. In this way, service-pack-based and service-module-based logistics spacecraft will be distinguished.

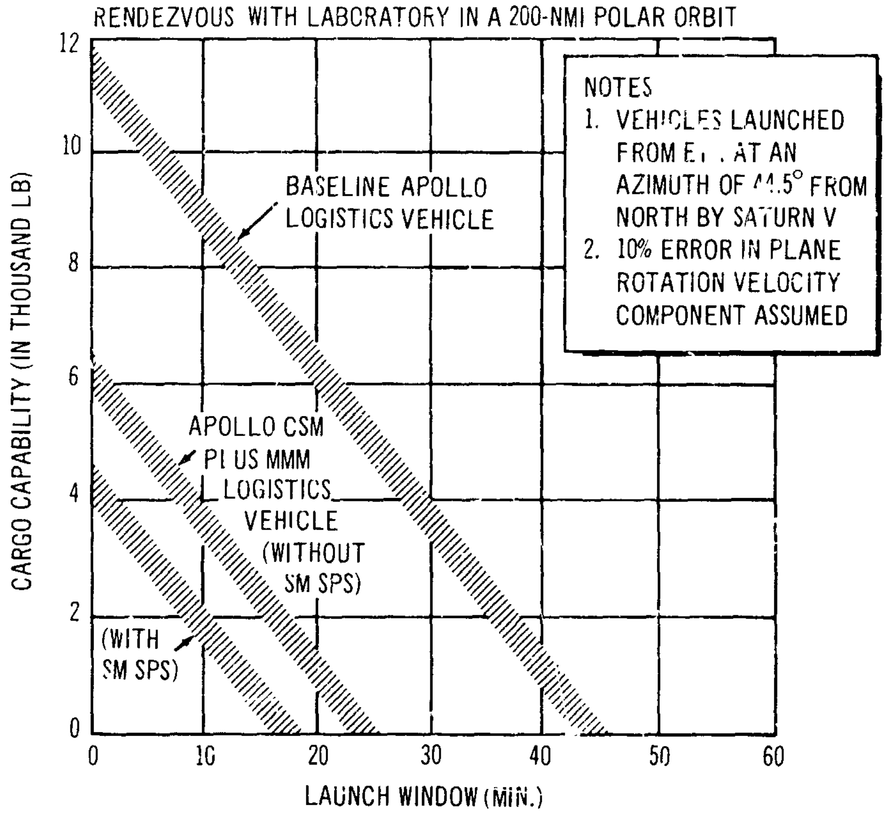


Figure 4-26. Cargo Penalty as a Function of Launch Window

4.4.4.2 Service Pack-Based Logistics Vehicles

The spacecraft portion of this logistics vehicle (the command module, service pack, and multimission module) is essentially identical to the baseline vehicle described for the 50° inclination mission. The only differences are caused by the slightly higher impulsive velocity requirements for polar mission rendezvous and the weight of the vehicles being rendezvoused. Changes are required, therefore, in the propellant, pressurant, and associated tankage of the multimission module RCS. The only other change is to the fairing between the launch vehicle and the logistics spacecraft. The Saturn IB and V configurations use the 144.5-in. long baseline adapter between the S-IVB stage and the multimission module. An S-IC/S-II logistics launch configuration might use a S-II-S-IVB adapter attached to an S-IVB instrument unit (rather than remount the flight control units in an adapter), which is attached to the baseline fairing. Flight separation occurs at the aft end of the multimission module; all fairings go with the last expended stage after transfer orbit injection.

Saturn - IB Launched at 146° from ETR

Because of the launch vehicle's low payload capability in this mission, this configuration is only of interest as a potential ferry craft.

As noted previously, the logistics spacecraft is almost identical to the vehicle configured for the 50° inclination mission. The only difference is the multimission module RCS propellant. With a 5-min. launch window, the rendezvous impulsive velocity requirem[illegible]s 795 fps. Using an additional 190 fps for empty MMM deorbit and a 10% residual loss, the total propellant required is only 2,140 lb. Rather than resize the RCS tanks, it was assumed the baseline tanks were simply off-loaded for this special case. Discretionary payload is only 1,620 lb.

Saturn - IB Launched at 182° from WTR

This vehicle was configured to determine its cargo capability for use in a potential tradeoff of new facility expense versus continued Saturn V launches from ETR. The propellant weight was calculated as per the Saturn IB launch from ETR and differed simply because it has a heavier payload to rendezvous and deorbit. This configuration can deliver [illegible],060 lb of cargo to the polar orbit.

Saturn - IC/S-II Launched at 146° from ETR

The S-IC/S-II launched at this azimuth into a polar orbit has capability far in excess of that utilizable by the logistics vehicle. The cargo is only limited by the volume available in the multimission module. Assuming an average cargo density (liquid and solid) of 20 lb/cu ft and a volume of about 1,000 cu ft in the pressurized section, 20,000 lb is used as the maximum cargo for these excess capability configurations. The potential for heavier cargos exists, however; a nuclear reactor experiment in the MMM could weigh over 30,000 lb. This logistics vehicle configuration with adapters is shown in Figure 4-27.

The multimission module RCS was sized for a logistics spacecraft carrying 20,000 lb of cargo. Rendezvous impulsive velocity is 70 fps higher for this configuration because of potential second-stage thrust termination errors. Since the propellant required is significantly different from the baseline, the RCS propellant tanks and pressurant system were resized.

Saturn - V Launched at 146° from ETR

This logistics vehicle configuration is similar to the S-IC/S-II-launched Apollo baseline. Exceptions are the return to the one S-IVB/MMM adapter and removal of the S-II rendezvous penalty. The payload remains far in excess of the 20,000 lb the configuration is capable of carrying.

Saturn - V Launched at 44.5° from ETR

Since this logistics vehicle is almost identical to the Saturn IB-launched baseline Apollo for the 50° inclination mission it would be a natural choice for the polar mission. The only difference is a 10% increase of the MMM RCS requirements over the 50° inclination mission. If orderly progression from 50° to polar missions were assured, the logistics vehicle MMM RCS could be sized for the polar mission to begin with. At a small penalty, less than 100 lb to the 50° inclination mission, the same logistics vehicle serves both missions. This configuration can carry 10,220 lb of cargo to the orbiting polar laboratory

4.4.4.3 Service Module-Based Logistics Vehicles

This concept was first explored for the synchronous mission (Section 4.4.5) where there is need for a relatively large deorbit propulsion system, high cargo capability, and logistics mission flexibility. As a result, a configuration evolved that was simply an Apollo command and service module with a multimission module suspended from the aft end of the service module (inside a LEM adapter during boost phase) as shown in Figure 4-28.

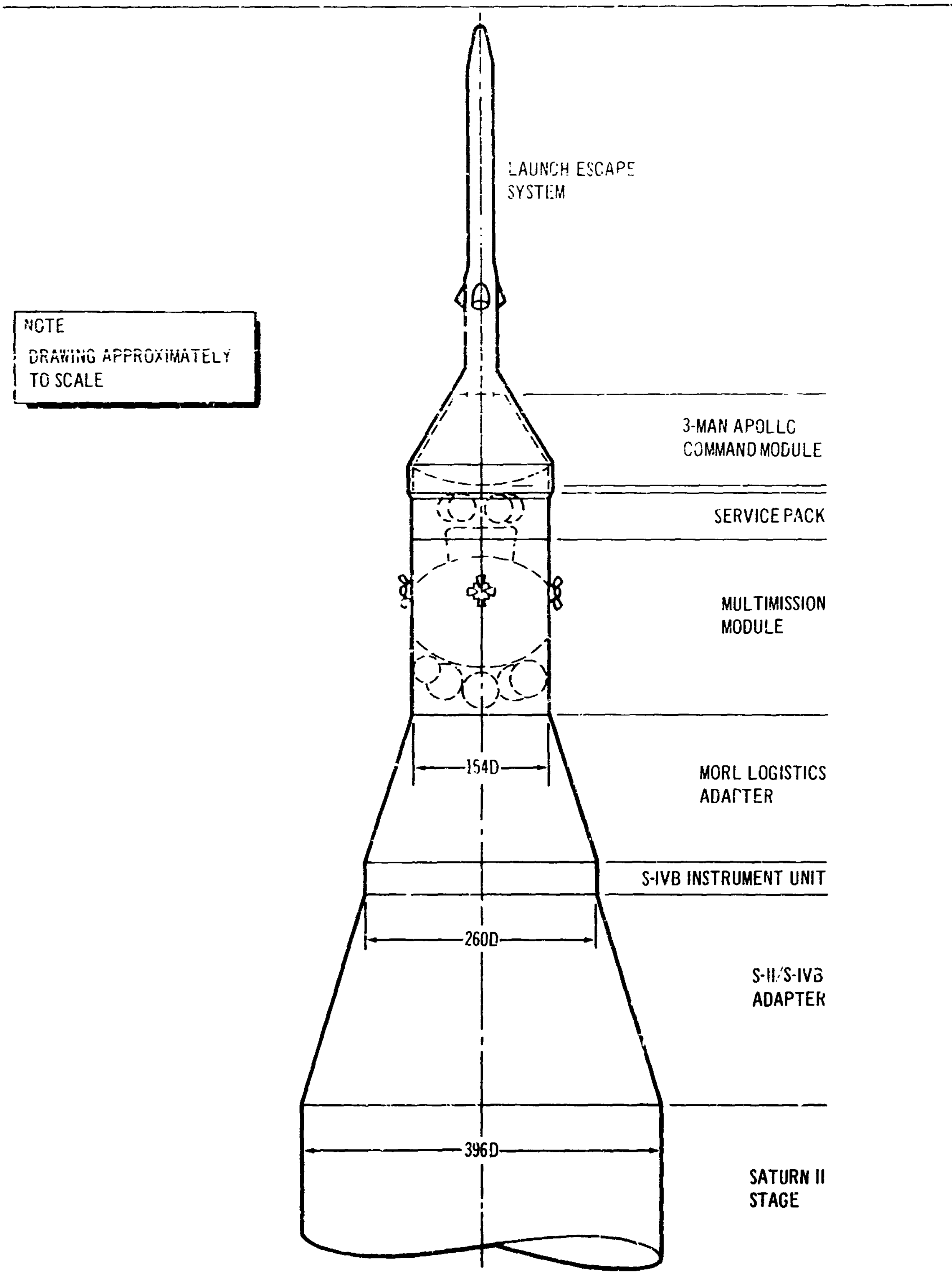


Figure 4-27. Two-Stage Saturn V (S-IC/S-II)/Baseline Apollo Logistics Vehicle

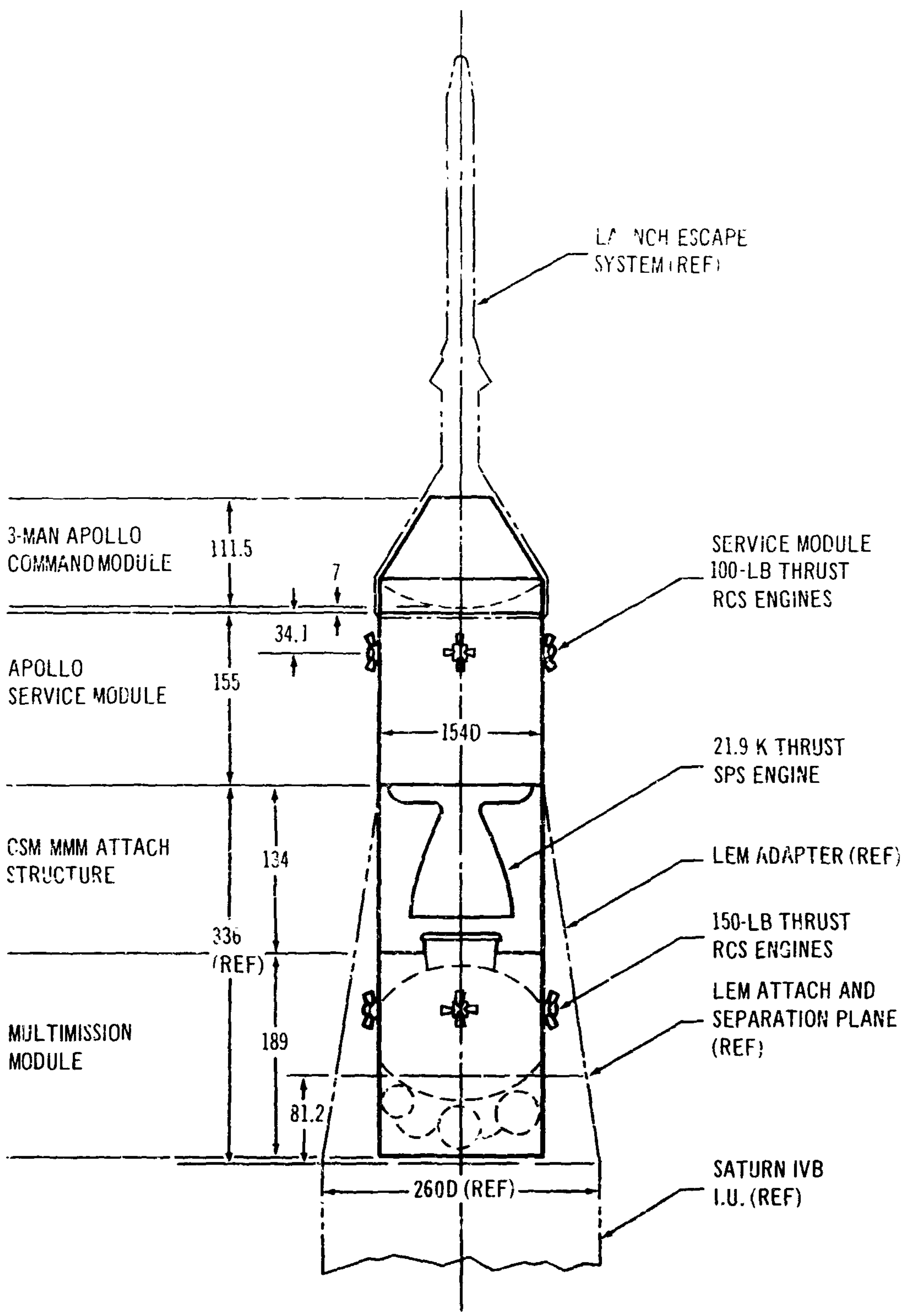


Figure 4-28. Modified Apollo Logistics Vehicle

Because the polar mission does not require a large deorbit velocity, the less complex, lighter baseline configuration utilizing the service pack is a more satisfactory approach. However, other mission plan considerations could dictate the use of one logistics vehicle configuration for both the polar and synchronous missions. For this reason, service module-based configurations were evaluated with different launch vehicles for the polar mission.

Saturn-IC/S-II Launched at 146° from ETR

The logistics vehicle, when launched in this high payload configuration, utilizes Apollo command and service modules with minimum modifications for the logistics mission.

Command module subsystem changes are the same as those discussed previously under the S-IB/Apollo CSM-derived logistics vehicle for the 50° mission (Section 4.4.3.3).

Service module modifications for this mission include adapting applicable subsystems to qualify for a 6-month orbital storage. Other mandatory subsystem modifications include the following:

1. Electrical power--Replace Apollo fuel cells with batteries for the 3-day ascent and 1-day descent phases. Modify power distribution system.
2. Environmental control/life support--Removal of fuel cell system requires addition of water and oxygen supply.
3. Instrumentation--Remove LEM monitoring instrumentation.

Note that the service propulsion system is left intact, even though only about 1,000 lb of propellant is required (for CSM deorbit).

An attach structure is required between the service module and the multimission module. This structure will probably be jettisoned after the logistics vehicle docks at the laboratory; the CSM and MMM will be handled separately.

The multimission module is used unmodified from the baseline concept except for the resizing of the reaction control system for this mission. RCS propellant requirements were based on an assumption that about half the SM RCS propellant is available for rendezvous and docking velocity, the rest is used to buck out the off-cg thrust of the MMM RCS and to perform CSM-unique maneuvers. Total rendezvous velocity requirements are 865 fps for the S-IC/S-II-launched vehicle at a 5-min. launch window. Cargo capability is limited by MMM volume to 20,000 lb.

Saturn-V Launched at 146° from ETR

This configuration is essentially the same as the S-IC/S-II-launched vehicle just discussed. The only differences are as follows:

1. Multimission module RCS is sized to a slightly different requirement: a rendezvous velocity of 795 fps at the 5-min. launch window.
2. The only adapter required is the LEM fairing from the S-IVB stage to the service module.

Cargo capability is again limited to 20,000 lb.

Saturn-V Launched at 44.5° from ETR

This configuration requires, because of launch vehicle payload restrictions, extensive modification of the service module service propulsion system in order to save weight. Also, because of the limited cargo that can be carried, as well as the SM SPS reduction, the weight to be rendezvoused is about 4,000 lb less than the previously discussed configurations. As a result, the multimission module reaction control system requires less propellant and can be resized downward from the baseline configuration. The service module SPS weight is based on the AES minimum tankage system of Reference 6.

With these changes, this configuration can carry about 3,000 lb of cargo. Because the service propulsion system is only used for CSM deorbit, a further attempt at weight reduction was made by substituting a MODAP-type command module retropack for the SPS in the configuration.

This allows the whole SPS to be deleted from the service module and the CSM/MMM attach structure to be shortened. The MMM RCS increases slightly because there is potentially more cargo to be deorbited with the MMM. The changes allow a grand total of 4,960 lb of cargo to be carried to the polar laboratory. A combination of Saturn V launch costs, extensive Apollo service module modifications, and low cargo capability make this configuration a doubtful candidate.

4.4.4.4 Proposed Vehicle

The baseline Apollo logistics spacecraft launched by a Saturn V at an azimuth of 44.5° from ETR appears to be the best choice at this time for the following reasons:

1. No significant range safety problems.
2. Simple, flexible logistics vehicle configuration.
3. Adequate cargo capability (over 10,000 lb).

A second choice would be the modified Apollo (CSM + MMM) launched by a Saturn V at an azimuth of 146° from ETR. Though this concept offers more cargo capability than the configuration is presently capable of handling, it has the following two disadvantages:

1. The configuration is more complex, heavier, and more awkward to handle (after docking at the laboratory) than the baseline Apollo.
2. The launch azimuth required may create range safety problems because of overfly and IIP across Cuba and Panama.

4.4.5 Synchronous Mission

4.4.5.1 Mission Profile Effects

Details of the mission profile are given in Section 4.2. The only launch vehicle considered capable of delivering an adequate payload for this mission is the Saturn V. The logistics spacecraft propulsion system is required to furnish only 202 fps of rendezvous and docking velocity if a 2-min. ground launch window can be met. Rendezvous will require between 2 and 3 days.

A major requirement for the logistics vehicle is that a high thrust system must provide an impulsive velocity of 4,920 fps for command module deorbit. An unmanned module, such as a depleted multimission module, will not be deorbited because of the weight and complexity penalties involved. They will simply be thrust into a different orbit. At near-synchronous altitudes, the volume of space involved provides an effective disposal.

4.4.5.2 Saturn-V/Apollo Logistics Vehicle

The concept that evolved for this mission is made up of a modified Block II Apollo command and service module with a MORL multimission module supported from the aft end of the service module. The MMM hangs inside a LEM adapter during the launch phase. The adapter will clamshell open to free the logistics spacecraft when it thrusts away from the burned out S-IVB stage during its first rendezvous maneuver. The configuration is nearly identical to the one shown in Figure 4-28 for a polar mission.

The three-man lunar Apollo command module must receive essentially the same modifications that were required for the baseline MORL logistics mission (Reference 9, pages 101 and 102). Exceptions are that the command module may be exposed to space for up to 6 months and no retro-pack is needed for deorbit. The 4.5 g/sq cm (average) shielding of the command module structure and permanent equipment results in approximately 1 rad of radiation on transit through the radiation belts. It is thus deemed more than adequate (Reference 10 pages 137 and 138).

Modifications to the Apollo service module for the synchronous logistics mission include the following:

1. The service module systems must be adapted to a staytime in orbit of up to 6 months.
2. The fuel cells must be replaced with batteries for Apollo CSM ascent and descent power requirements. This also forces modifications to the EC/LS system.
3. EC/LS consumables must be furnished for a 3-day duration ascent phase and a 2-day maximum duration descent phase.

4. The service propulsion system must be kept to provide deorbit impulse. The propellant tanks could be resized to the 11,600 lb of propellant required for deorbit (the lunar mission requires about 37,000 lb of propellant). However, the expense of modification was not considered worth the more than 1,000 lb of tank and pressurant system weight that could be saved, and the SPS was left unmodified.

5. Some modification to the service module electronics because of the new mission is also required.

An attach structure between the service module and the multimission module is required. This logistics vehicle configuration will also require redesign of the Phase IIa MORL handling arms.

The multimission module from the Phase II baseline configuration can be used without modification. Reaction control system propellant requirements were based on 202 fps for rendezvous and 200 fps for MMM disposal. The service module RCS was not assumed to furnish any velocity for rendezvous, its thrust being used to buck off-cg MMM RCS thrust and perform CSM unique maneuvers. These requirements result in a propellant weight which is about 40% less than baseline. However, since the baseline MMM RCS appears adequate for the 50° inclination mission, the propellant is off-loaded for the synchronous mission, and the RCS can remain unmodified.

The modified Apollo logistics vehicle launched by an Saturn V appears quite satisfactory for the mission since it furnishes about 19,000 lb of cargo capability for the synchronous mission.

4.4.6 Logistics System Inventory

The baseline logistics system represents a sizable portion of the total MORL system. The operating costs of MORL (estimated to be $365 million per year) are largely incurred by the required logistics flights. The current logistics flight schedule is based on a 180 day average stay time for each crewman which was imposed for biomedical reasons. With the three-man Apollo, four flights per year are required to rotate the crew in accordance with this stay time. For 5 years of operation, 22 logistics vehicles are needed (4 per year plus the initial 2 manning launches).

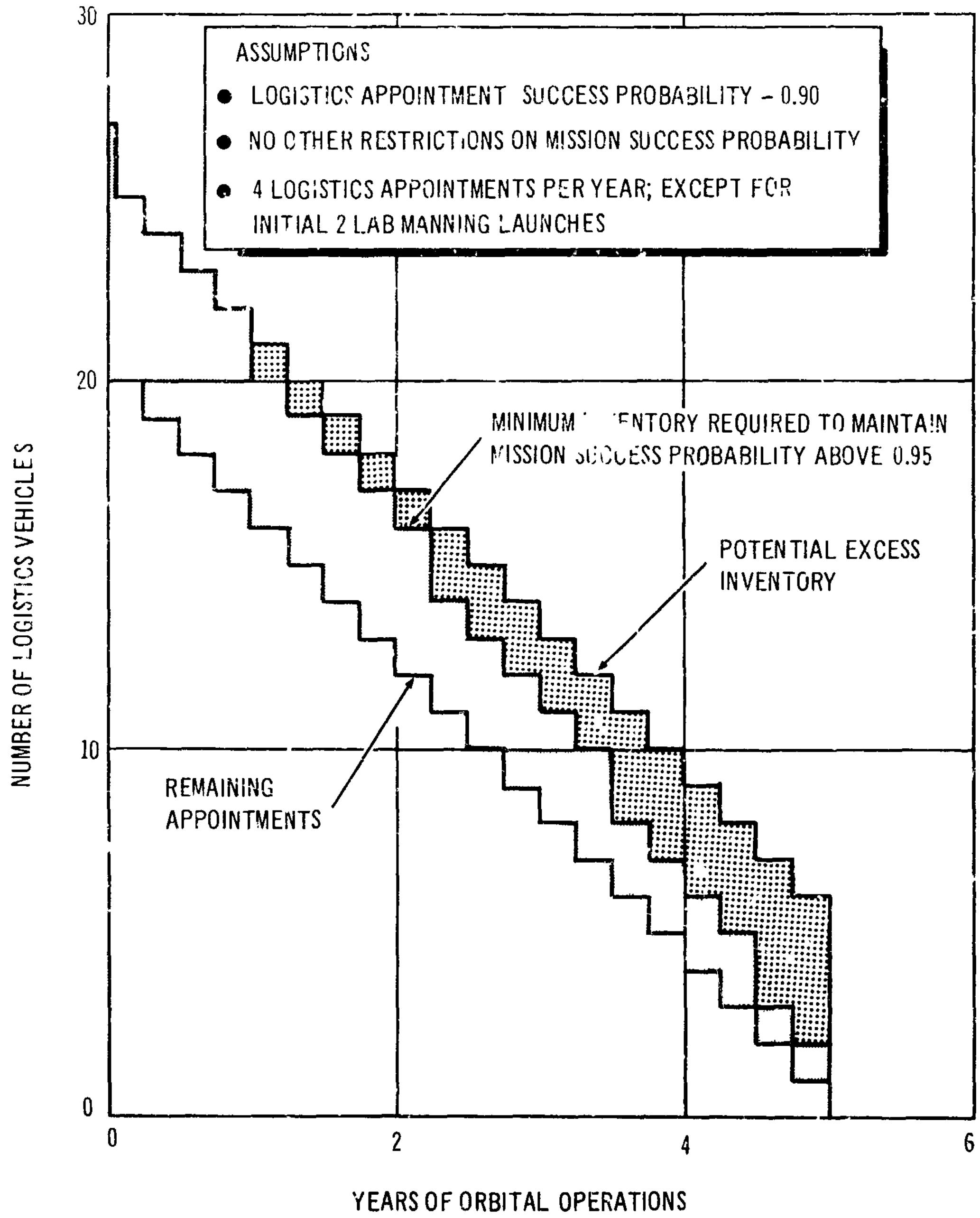


Figure 4-29. Logistics Vehicle Inventory Required During a Five–Year Mission

If the complete logistics vehicle inventory were purchased at the start of the 5-year program, a 0.95 probability of meeting all 22 appointments (with a logistics system that has a launch, rendezvous and dock success probability of 0.90) requires that at least 27 vehicles be available. This initial inventory of 27 vehicles is 5 more than required if all launches are successful. As the program progresses in time the number of remaining appointments decreases and the number of excess vehicles required to assure the mission appointment success probability of 0.95 also decreases. For instance, in the last year of operation there are only four appointments, and the inventory required for a success probability of 0.95 is six. If all the launches were a success up to that point there would be nine vehicles available -- three more than required. This is shown graphically in Figure 4-29. The bottom stairstep gives the number of appointments remaining as a function of mission duration. The next stairstep shows the total number of vehicles that must be in inventory at any point in time to assure that the remainder of the mission has a success probability of at least 0.95. Because we are dealing with integer units (whole logistics vehicles) success probability is usually above 0.95 and the required inventory can sometimes drop two vehicles, when only one was launched, and still maintain the 0.95 probability; e.g. at the end of Year 1. The final stairstep shows the potential excess inventory assuming all launches were successful.

The figure was based on the following analysis: For K appointments remaining in the mission and using a logistics vehicle with a probability of success, P_L, the number of vehicles (N) required to assure an overall mission (appointment) success probability is generated as a byproduct of the mathematical solution to the generalized inventory-appointment problem. The generalized inventory-appointment problem is stated as the probability of meeting K appointments (i.e. mission success) with at most N vehicles, each of which has success probability P_L, and with at most L attempts per appointment. An analytical expression for the solution to this problem is given below:

$$P_s = \sum_{i=K}^{N} \left[P_L{}^K Q^{i-K} \left[\binom{i-1}{i-K} - K\binom{i-L-1}{i-K-L} + \frac{K(K-1)}{2!} \binom{i-2L-1}{i-K-2L} - (-1)^{n-1} \right. \right.$$

$$\ldots \frac{(K)(K-1)(K-2)}{(n-1)!} \ldots (K+n-2)\binom{i-(n-1)L-1}{i-K-(n-1)L}\Bigg]\Bigg]$$

where:

$Q = 1-P_L$

n = the number of terms in the coefficient.

For any i, n must be such that $(n-1)\,L + K \le i < nL + K$

This expression may be derived by generating functions to express the probability of success in a single appointment. The probability of K successful appointments may then be expressed as the product of the probabilities of each appointment.

By evaluating this expression for K appointments and L attempts per appointment (L is assumed large in Figure 4-28), an N can be found such that if the probability of each successful launch is 0.90, the probability of mission success is 0.95 or greater.

Table 4-20 shows the probability of having in inventory, at the beginning of each year, n vehicles more than is required to maintain the mission success probability of 0.95. This excess is of course due to few or no failures in the previous year, or years, of operation. For example, if in the 1st year of operation all 6 logistics launches are successful, the inventory at the end of that year is reduced to 21, yet only 20 are needed to ensure a 0.95 probability of successfully completing the remaining 16 launches. The remaining logistics vehicle is available for other purposes without compromising the success of the main mission.

These excess logistics vehicles could be used to provide MORL with a nine man crew for brief periods. The extra manhours resulting could significantly increase the inspace capability of the MORL. The potential increase in manhours added to the MORL program is shown below.

Number of Vehicles	Experimental Man-Hours Made Available
1	4,120
2	8,240
3	12,370
4	16,490
5	20,610

It should be pointed out that these extra manhours are provided without additional logistics system vehicle purchases and without compromising the overall mission success probability.

An alternate use for these potentially excess logistics vehicles would be to increase the orbital life of the MORL beyond five years without additional purchases. At the end of the 5 year program, the probability that there would be three excess logistics vehicles is 0.56. Three vehicles would provide sufficient inventory for a 0.95 probability of two more successful launches, or six months more orbital stay time for MORL.

Table 4-20

PROBABILITY OF AVAILABILITY

Notes
1. Mission appointment success probability is 0.95 or greater
2. Logistics appointment success proability = 0.90
3. 180-day crew rotation assumed.

	Years of Remaining Orbital Operations				
Vehicles*	4	3	2	1	0
5	0	0	0	0	0.10
4	0	0	0	0	0.32
3	0	0	0	0.15	0.56
2	0	0	0.23	0.42	0.76
1	0.53	0.35	0.55	0.68	0.89

*Number of vehicles in inventory (n) beyond that required for mission success probability of 0.95.

Section 5

SUBSYSTEM ACCOMMODATION OF EXPERIMENTAL REQUIREMENTS

This section describes the ability of the MORL system to meet the requirements of the experiments in the Experiment Plan plus certain additional experiments.

All sources of the experiments in this plan were reviewed to determine a meaningful set of experiment performance requirements to be imposed on the MORL and its subsystems. This review yielded a spectrum of requirements that can be accommodated by the baseline MORL system with the following reservations:

1. A separate EC/LS temperature control and ventilating system should be installed in the hangar section to provide adequate comfort and control during the increased occupancy of this section due to the experiment requirements. The system would be similar to the main laboratory temperature control and ventilation system.

2. Experiments that require high slew rates or precise rate stabilization should be gimbal mounted. In addition, a rigid common mount should be provided for the precision attitude reference and those experiment sensors requiring less than 0.5° attitude error.

3. The Baseline Data Management System capacity must be enlarged in order to accommodate the experiment requirements. The following four areas should be investigated to determine their effectiveness in accomplishing this enlargement:

   A. A single, programmable data acquisition and distribution function that is central to all other subfunctions.
   B. An all-digital data distribution bus with local (signal source) analog to digital conversion.
   C. A single data channel telemetry function with interrupt capability.
   D. The capability to reduce on-board operational and experimental data.

4. In order to accommodate experiments performed in the hangar section, a new console and operator panel should be installed. The laboratory scientific console should also be enlarged to provide adequate multiple experiment control capability.

5.1 ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEM (EC/LS)

The EC/LS System was found to be adequate to accommodate the requirements of the Experiment Plan. However, it is recommended that a separate cooling and ventilation circuit be installed in the hangar to provide better control and comfort for the increased occupancy of this area because of the experimental program. The system would be similar to the one in the main laboratory.

5.1.1 Experiment Requirements

The original experimental program that was considered for Phase IIa influenced the design of the baseline EC/LS system. The specific changes made to the original design concept are summarized below for reference.

5.1.1.1 Atmospheric Supply

The atmospheric losses due to equipment lock, man lock, and hangar decompressions for the experimental program are accounted for in the sizing of the cryogenic O_2 and N_2 tanks. Additional O_2 and N_2 are resupplied accordingly.

5.1.1.2 Atmospheric Purification

The Biological/Liquids Laboratory was created for containment of dangerous liquids and contaminants within a single compartment. A separate purification circuit was added to this compartment.

5.1.1.3 Compartment Conditioning

The purification circuit in the Biological/Liquids Laboratory also provides for temperature control and ventilation.

5.1.1.4 Water Management

The excess water recovery (over and above normal crew requirements) is used for all experiments requiring water. In addition, this excess water provides for back-pack cooling for experiments requiring extravehicular operations.

5.1.1.5 Waste Management

The waste dehydration capacity normally required for the crew wastes is arbitrarily doubled by adding a duplicate set of dryers in the experimental area to handle experimental wastes.

A 2-cu ft, $0^{o}F$ freezer was added to the laboratory equipment because of experimental low temperature storage requirements. The refrigeration ($40^{o}F$) capacity was doubled to a 3-cu ft volume.

When the expanded experimental program was examined for its impact upon the EC/LS system, it was found that while the number of experiments to be accomplished greatly expanded, the categories or types of experiments did not. Therefore, if the EC/LS system could already accommodate all original categories, the additional experiments could be expected to impose no penalty. This trend is expected to continue as the experimental program changes. One change in laboratory operation is suggested, however, by the expanded experimental program. The applications plan experiments indicated that a greater number of experiments would require looking at the Earth. Since these Earth-oriented experiments will generally be conducted in the hangar, it appeared that the hangar's use as an experimental area would greatly increase. There is a greater possibility that four or six men would be in the hangar at one time and that more than one experiment will be conducted simultaneously.

5.1.2 Subsystem Capabilities and Potential Changes

It must be remembered that in the baseline EC/LS system the hangar atmospheric purification circuit is utilized to provide temperature control and ventilation. Because this circuit is designed for the closed suit loop operating mode, its usefulness as a hangar conditioning circuit is limited. With two men in the hangar the air temperature would remain at about 75°F. However, with four or six men, plus electrical heat dissipation, the hangar air temperature could reach 80° to 85°F, which would be uncomfortable for long-term occupancy. Therefore, it appears, that a separate cooling and ventilation circuit similar to that in the main laboratory is required for the hangar: this change is recommended for consideration in Task IV.

5.2 ELECTRICAL POWER

The electrical power system supplies the required power to operate the experimental program and to maintain the normal housekeeping loads. An evaluation of the electrical power required by the experiments was conducted. The data used for this analysis were obtained from the SPEED computer program and from detailed experimental load evaluation for the 48-hour study. Results of the evaluation show that the electrical power system has been designed to provide sufficient power for the operation of the experimental program.

The SPEED program that formed the Experiment Plan also periodically displayed the status of the electrical power system. The amount of electrical power being consumed by the experiments was examined once each 720 hours of time. The resultant data are shown in Figure 5-1. These data provide an instantaneous snapshot of the power being consumed at the stated intervals. The average experimental power consumption was also determined by SPEED; it is 91.3 W, as is also shown in Figure 5-1. The peak experiment load displayed is 1,000 W. The actual peak experiment power consumption measured during the Experiment Plan simulation was 2,205 W.

An allowance for an average power of 2,000 W was provided for experiments in the design of the electrical power system. The electrical power system also has the capability of providing 150% of rated power for periods up to 1 hour (see Figure 4-12) or smaller amounts of overloads for longer periods of time. Therefore, all experimental power requirements are within the provided design capability of the MORL electrical power system.

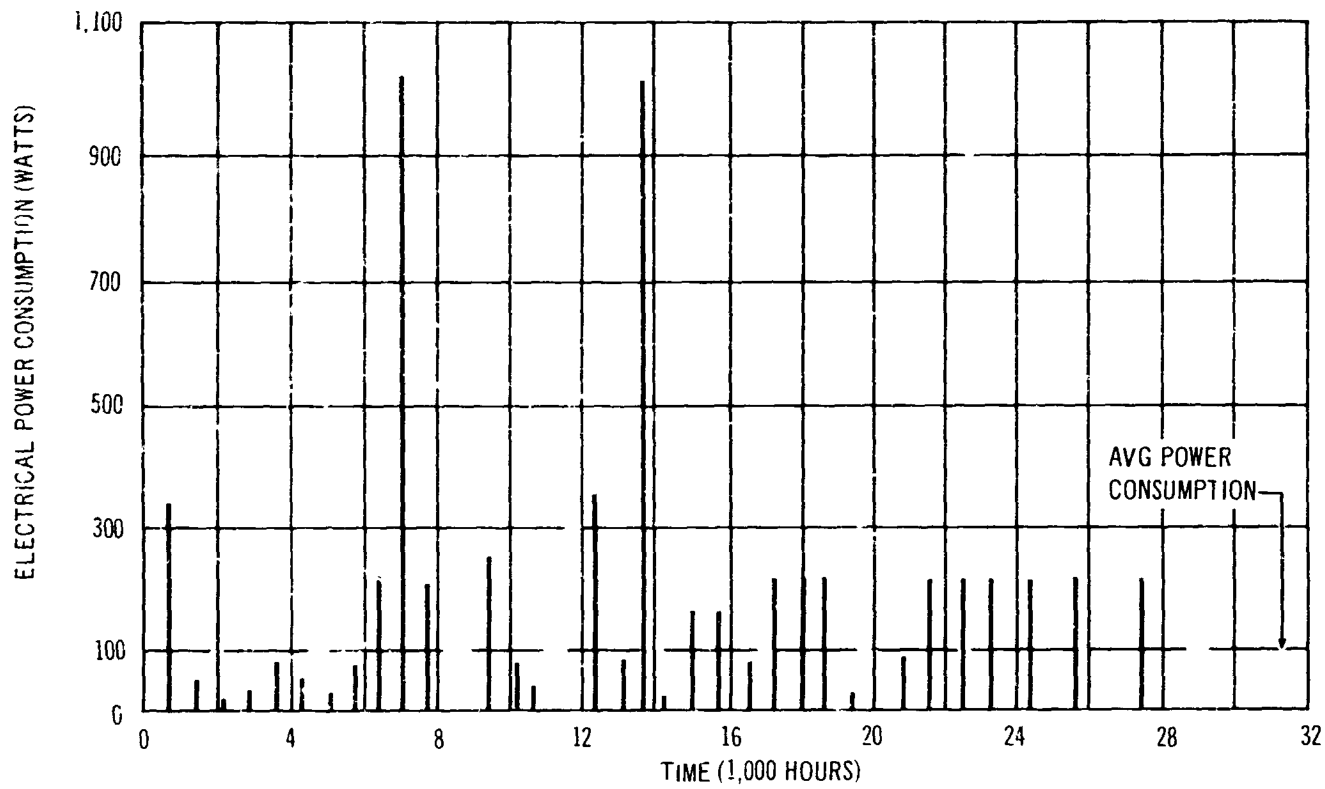


Figure 5-1. Electrical Power Consumption Experiment

5.3 STABILIZATION AND CONTROL SYSTEM (SCS)

The Stabilization and Control System can meet all pointing requirements of the experimental program, provided that a gimballed experiment mount is furnished for some of the experiments, that 8 of the 163 experiments examined are supplied with their own error sensors, and that a rigid sensor-experiment beam is installed.

5.3.1 Responsiveness Analysis

The MORL data bank of 163 experiments was examined to determine the entire spectrum of requirements that may be imposed on the Stabilization and Control System by the experiments. Each experiment was examined in detail to determine the requirements for vehicle orientation, pointing accuracy, duty cycle, stabilization, slewing rates, and other pertinent factors. It is assumed that the data bank list of experiments represents a worst-case set of requirements and thus forms a better framework for evaluating the SCS than would be provided by a more restricted list associated with a specific mission.

The data bank consists of 163 different experiments derived from three major study programs: the MORL phases IIa and IIb, the Apollo extension, and the Orbiting Space Station. The specific sources from which the data bank experiments were generated are listed below:

1. Douglas MORL Program
   - A. Douglas Phase IIa studies.
   - B. Communications--IBM study.
   - C. Meteorology--Douglas in-house study.
   - D. Oceanography--Bisset-Berman and Marine Advisors study.
   - E. Geophysics--Douglas in-house study.
   - F. Cartography--Aero Service study.
2. Apollo Extension Program
   - A. North American Aviation Extended Apollo studies.
   - B. NASA, AES studies.
3. Orbiting Space Station Program
   - A. Douglas OSS studies.
   - B. General Electric OSS studies.
   - C. Space System Division OSS studies by Martin-Marietta.

Approximately 700 experiments contained in these sources were summarized and categorized into the following nine major groups (these have since been regrouped under four major headings):

	Group	No. of Experiments/Group
I	Biomedical	3
II	Behavioral	9
III	Biological	22
IV	Space Measurements and Astronomy	8
V	Earth and Earth Surface	7
VI	Materials Testing and Physics	26
VII	Subsystem Testing	69
VIII	Logistics/Space Operations	13
IX	Spacecraft Environment	6
	Total	163

In many cases the reference source descriptions for a particular experiment varied widely in specified SCS requirements (in other words, many experiment definitions lacked sufficient detail or conflicting rate and attitude hold requirements for the same experiment, and many called for gimballing of experiment packages without regard to vehicle capability). In general, when the reference source descriptions specified different attitude or rate requirements for the same experiment, the most stringent specifications were used.

Table 5-1 is a sample data sheet containing summary SCS requirements extracted from six unclassified experiment categories in the data bank. This sample is included to show the format used and to indicate the quantity of data involved in the accommodation assessment. Since many of the experiments are classified Secret or Confidential, the complete lists of summary data have not been included in this report.

In Table 5-1, Experiment Definition refers to the experiment title and category to which the experiment is assigned in the data bank.

Orientation is the vehicle or sensor attitude orientation required by the experiment. In more cases where an Earth orientation is specified, it is assumed that the belly-down orientation satisfies the requirement.

Pointing Accuracy refers to the alignment accuracy required between the sensor and the selected attitude reference. The required accuracy may be obtained by using the laboratory as a pointing platform or by gimballing the experiment sensor relative to the laboratory.

Field of View is the angular coverage required by the experiment sensor. Both instantaneous and total field of view requirements should be specified for each pointing-type experiment.

The Rate column includes specifications for the maximum rate relative to the selected attitude reference that is permitted during operation of the experiment, and the specifications for slewing or rotating the sensor axis relative to the selected attitude reference.

Table 5-1
EXPERIMENT DATA SHEET

Experiment Definition	Orientation	Pointing Accuracy	Field of View	Rate	Navigation	Duty Cycle	Integral Gimbals	Manual or Auto Control	Notes
VII-62 (UBL) IB-4 Sea color distribution	Belly down	Spacecraft - 0.01 desired	Telescope to be slewed ± 60 perpendicular to orbit plane and ± 10° from L. V. in orbit plane	Spacecraft stability - 1°/sec	Position to 1 nmi Time ref to 0.1 sec	2 hr/day for 7 days	Yes	Manual and auto pointing of telescopes	High resolution telescope (1 arc sec) with 1° x 1° f. o. v. mounted on gimbals inside MORL.
VI-26 IA-4 Auroral survey	Belly down - point sensors to polar regions	Not specified - assume 0.5° req by experiment	10-in. optical window	Not specified assume 0.10°/sec	Not specified	Experiment continuous for 1 year. 1.5 hr/month crew required	Yes	Manual	High inclination and synchronous orbits
VII-9 IIIB-10 (I-3) Microwave experiments	Belly down	0.1° all axes		0.01°/sec 3 axes 0.01° dead-band	Time ref 0.02 sec 0.2 nmi	1 hr/day each day for 1 year			See phase IIA exp Earth Radar Mapping
VII-59 (UBL) IIB-6 Subsurface oceanographic parameters	Belly down	Consistent with 2° overall accuracy for up to 3/4 hr/experiment (assume 0.5° spacecraft pointing accuracy)	4-ft antenna to be slewed ± 72° about L. V. (horizon to horizon)	Spacecraft rate stability ± 1°/sec over 30 sec slewing 1.5°/sec during track and 5°/sec during repositioning	1 kilometer	1 hr/day for 60 days	4-ft parabolic antenna	Manual and auto control of antenna	The attitude of the antenna relative to the buoy must be to within ± 2.0°. As many as 10 different buoys may have to be acquired and tracked in a 5 min period.
VII-60 (UBL) IIB-3 Two-dimension temperature spectrum of ocean surface	Belly down	Spacecraft pointing accuracy 0.01° (0.1 acceptable)	Two sets of sensors. 1 ± 45° gimbal x about L. V. 2 ± 72° gimbal x about L. V.	Stability ± 0.01/sec for 2 min slewing capability of 5°/sec	Time reference to 0.2 sec or better Position coordinates 1 nmi or better	1/2 hr/exp. 4 times/day for 50 days	Yes	Manual and auto control of sensors	Narrow field of view infrared sensor system. (5 heads with coincident 5 x 5° f. o. v.) Also a 0.01 sensor.
VII-61 (UBL) IIB-5 Surface salinity spectrum determination	Belly down	Spacecraft - pointing to ± 2°	Consistent with gimballed 4-ft antenna ± 72° (two axes)	0.1°/sec slew up to 5°/sec	Position to 1 mi time ref to 0.02 sec	6 hr/day for 10 days while passing over oceans	4-ft antenna mounted on ± 72° gimbals	Manual control of antenna	Transponder satellite launched from MORL in MORL orbit plane

The navigation requirements, specified in terms of position and time measurement accuracies, are listed in the next column. Although navigation is not an SCS function, it is sometimes useful to know the allowable position error, particularly when pointing accuracy or rate requirements are not specified and must be estimated.

Duty Cycle refers to the operating/nonoperating time sequence. This is useful in cases where attitude reference error is a function of time and the drift during experiment operation must be determined.

Many of the experiment descriptions specify integral gimbals, which means that the experiment sensor may be rotated about one or more axes relative to the body of the laboratory. Specification of gimbals by the experimentor presupposes limitations on the laboratory pointing capabilities. While this is usually a valid assumption, it is nonetheless required that the basic experiment requirements be checked against the laboratory capabilities before specifying the need for a gimballed mount.

The last significant column, Manual or Auto Control, is listed briefly to indicate the role of man in experiment control. For most experiments, this division is not clearly defined.

In summary, it is noted that the experiments as currently defined do not spell out requirements for stabilization and control in much detail and, consequently, many of the control requirements must be estimated on the basis of what information is given. While the data bank list of 163 experiments may not represent any specific experiment program or plan, it does provide a look at what may be considered the complete spectrum of requirements and, as such, represents a good set of criteria against which the SCS concept may be evaluated.

5.3.2 Requirements Accommodation

In determing the degree of accommodation afforded experiments by the SCS, primary attention is given to the attitude and rate requirements. Of the 1963 Phase IIa data bank experiments examined, 102 impose some requirement on the Stabilization and Control System; 101 require pointing, attitude hold, or knowledge of attitude history, 101 require a rate stabilization capability and, of these, 43 also require a slewing capability in excess of 1°/sec. The distribution of these requirements is shown in Figures 5-2 and 5-3, respectively.

It was assumed that the laboratory/experiment interface would be simplified if the experiment could utilize the laboratory itself as an orientation and stabilization platform and not be required to provide its own control functions. Therefore, the pointing accuracy and rate requirements for a given experiment are first compared with the laboratory's pointing accuracy and rate capabilities. In the horizon sensor/gyrocompass mode, the baseline SCS can maintain the laboratory's axes aligned to within 1/2° of the belly-down reference orientation. Body rates are largely a function of the transient disturbances induced by crew and equipment motions. Although this disturbance category has not been studied in depth, it is anticipated that vehicle rates at least as high as 0.06°/sec will be experienced due to crew motions. By restricting crew activity somewhat, the vehicle rates may be reduced to 0.01°/sec or even 0.005°/sec. These attitude hold and rate capabilities of the laboratory are also shown in Figures 5-2 and 5-3, respectively.

Figure 5-2 shows that 54 experiments have pointing requirements within the 1/2° capability provided by the SCS horizon sensor/gyrocompass mode. However, 41 of these 54 experiments, when located in Figure 5-2, have stabilization rate or slewing requirements that exceed the baseline capability; thus, only 13 can be accommodated by direct control by means of the laboratory SCS.

The precision attitude reference that consists of an inertial platform, star-tracker, and computer can control the laboratory axes to within 0.1° attitude error. In order to provide this pointing accuracy for a given experimental instrument, the instrument and the star tracker must be mounted on a common rigid mount to avoid misalignment caused by structural flexure and displacement. With this 0.1° capability, it is seen from Figure 5-2 that the number of experiments that can be accommodated is increased by 33

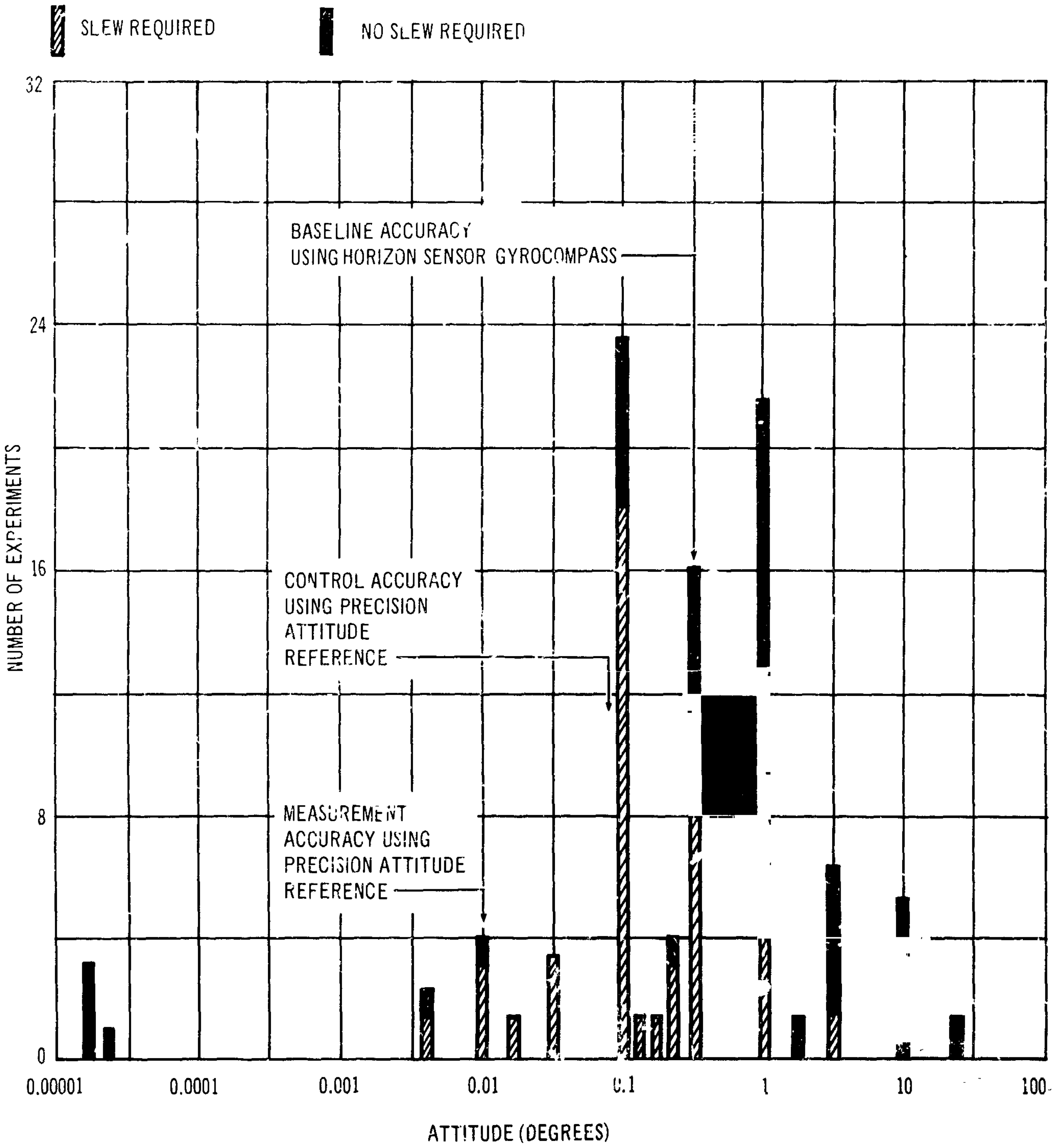


Figure 5-2. MORL Experiment Requirements – Attitude

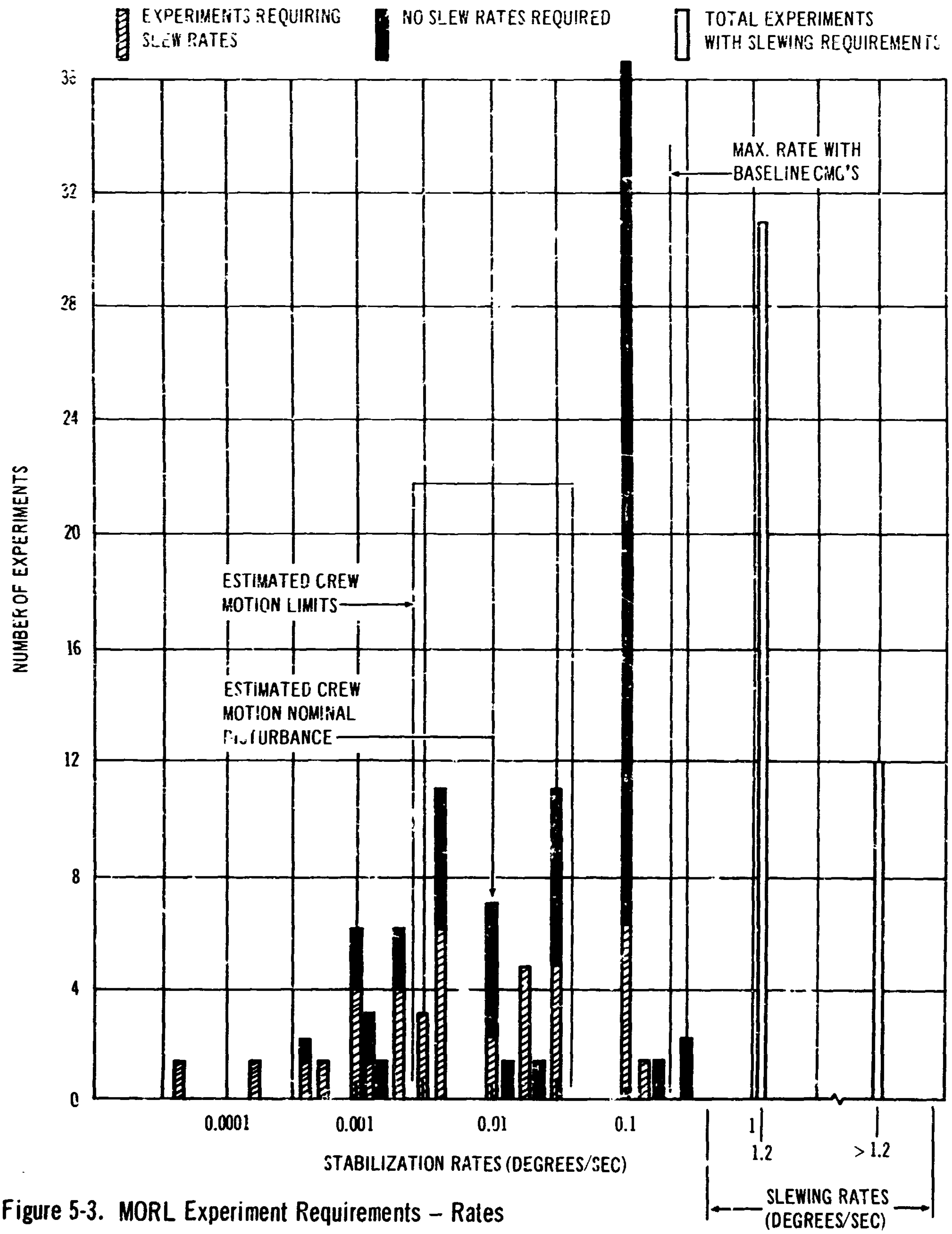


Figure 5-3. MORL Experiment Requirements – Rates

over that accommodated by the 0.5° capability. However, when these 33 experiments are examined in Figure 5-3, the number that can be accommodated is reduced to 10 since 23 exceed the slew rate capabilities of the CMG's.

These 64 experiments that cannot be accommodated because of their stabilization rate or high slew rate requirements could be gimbal mounted and controlled or slewed at the required rates with respect to the laboratory.

The high slew rate requirements also can be met by an increase in the size of the control moment gyro or by the use of the reaction control system engines for slew control. In order to achieve the rates required, the CMG's must be increased 100% in size to a total of about 300 lb. The propellant required to slew the entire laboratory through the required rate profile is about 10 lb per tracking event. If each of the 43 experiments requiring high slew rate were performed only one time, the propellant required would be about 500 lb. On the basis of this comparison of the two methods of slewing the laboratory, it is recommended that the experiment sensors be gimbal mounted and the entire laboratory not be slewed. This applies to all other experiments which have slewing requirements in excess of 0.3 to 0.4°/sec, which is the baseline momentum storage system limit.

If the attitude control accuracy were further extended from 0.1 to 0.01°, the current measurement accuracy limit, eight additional experiments could be accommodated as shown in Figure 5-2. Further examination of Figure 5-2 reveals that six of the eight experiments must also be gimbal mounted in order to satisfy their high slew rate requirements.

It can be concluded that the baseline system with a 0.1° pointing accuracy and the use of gimbal mounts can accommodate the pointing requirements of 87 of the 101 experiments, or 86%. Increasing the accuracy to 0.01° increases the number to 95 for a total of 94% (assuming these last eight are gimbal mounted). The remaining six experiments are beyond the accuracy capabilities provided by the baseline SCS. Fortunately, four of these provide their own control error signals. The remaining two use manual pointing, although the ability to meet these requirements by manual pointing remains to be proved.

One experiment (I-2, Conditioning Devices and Techniques) of the 102 requires only rate control (no attitude), and one experiment (VI-II, Solar Absorptivity and Thermal Emissivity of Thermal Control Coating) requires only attitude control (no rate).

The accommodation assessment may be summarized as follows:

Total experiments	163
SCS support required	102
Number requiring attitude control	101
Number requiring rate control	101
Number requiring gimbals	56
1. To meet slewing requirements	43
2. To meet attitude hold accuracy requirements	6
3. To meet rate hold accuracy requirements	7
Number accommodated by attitude hold of 0.5°	
1. No gimbals	41
2. With gimbals	54
Number accommodated by attitude hold of 0.1°	
1. No gimbals	53
2. With gimbals	95
Number accommodated with rate disturbances of 0.06°/sec (no gimbals)	34
Number accommodated with rate disturbance of 0.01°/sec (no gimbals)	47
Number accommodated with rate disturbance of 0.005°/sec (no gimbals)	52
Number accommodated with rate sensing threshold of 0.0006°/sec (with gimbals)	99

The remaining experiments, six from the attitude chart and two from the rate chart, must provide their own error sensing and must be gimballed for dynamic isolation or slewing purposes. The eight experiments, as defined, provide these functions. From these results, it is concluded that all experiments can be accommodated from the standpoints of attitude, rate, and orientation requirements.

5.3.3 Recommended Baseline Changes

All experiments that require a particular orientation can be accommodated by the baseline, and no change in the present system is necessary to provide the attitude capability. Since about 80% of the SCS experiments require an Earth-centered reference, the belly-down orientation is recommended for long-term use.

As indicated in the previous section, for experiments requiring high slewing rates (on the order of 1°/sec or greater), large amounts of propellant will be consumed if the laboratory is driven at these rates (on the order of 10 lb per maneuver). Therefore, it is recommended that these experiment sensors be mounted on gimbals and the laboratory held fixed in attitude. The laboratory attitude hold or pointing accuracy need only be sufficient to prevent gimbal angle overtravel, owing to disturbances while conducting the experiment, or to position the object in the field of view of the sensor head. With this approach, all 43 experiments requiring high slewing rates can be accommodated with no change to the basic Stabilization and Control System.

With all slewing-type experiments supported on gimbals, and with the 0.1° pointing accuracy provided by the common sensor-instrument mount and 0.005°/sec rate stabilization accuracy, only 13 of the total of 102 experiments remain. Since either the pointing accuracy or rate requirements of these experiments are beyond the baseline's capability, these equipments must also be mounted on gimbals in order to provide adequate control. In this mode of operations, the baseline SCS measurement accuracies of 0.01° attitude and 0.0006°/sec rate may be used to provide control signals to the gimballed sensors. Even with this level of accuracy provided by the SCS, there are eight experiments that have attitude or rate measurements beyond the baseline's capabilities. Since these eight experiments provide their own attitude and rate error sensing, there is no requirement to upgrade the baseline SCS capability.

On the basis of this analysis the following items are recommended as changes to the baseline system: (1) provide a common rigid mount that can support the star tracker and those experiment instruments requiring between 0.1 and 0.5° altitude error, and (2) provide a gimbal mount system for those experiments requiring high slew rates or fine rate stabilization.

In addition, there are areas of study that should be pursued in order to increase the confidence in meeting the aforementioned requirements:

1. The ability of the SCS to control the laboratory to an accuracy of 0.5° in the horizon scanner/gyrocompass mode and 0.1° with the precision stellar-inertial reference should be subjected to further analysis. Rudimentary studies performed in this and prior phases indicate that these requirements can be met. More complex analyses covering all possible disturbance situations may reveal cases in which these requirements cannot be met without modifying the baseline SCS.

2. The estimates of crew motion-induced dynamic disturbances are based on simplified assumptions. Further study, simulation, and in-flight testing are needed to establish a more realistic model of the crew motion disturbance profile. If these disturbances are more severe than expected, major changes in the CMG torque and momentum sizes will be required.

3. The ability of the laboratory's precision attitude reference to provide attitude sensing accuracy to 0.01° and rate sensing accuracy to 0.0006°/sec is estimated on the basis of the current technology. More sophisticated studies and simulations are needed to determine whether these requirements can be met when realistic error sources associated with the hardware mechanization are taken into account. Such a performance analysis must encompass the navigational errors, mechanical alignment errors, and errors in the experimental equipment and other sources, since these all contribute to the performance capability of the system.

4. The feasibility of an inflight alignment and calibration method for the attitude reference and experiment sensors should be determined.

5. This accomodation assessment has covered only the basic SCS performance factors of attitude, rate, and orientation and, as noted above, has not been substantiated by an in-depth performance analysis. Such analysis would be beyond the scope of the present study. Additional factors related to the SCS, influence the feasibility and operations involved in performing these experiments and should be studied further to determine whether changes to the baseline SCS are required.

5.4 COMMUNICATION SYSTEM EXPERIMENT REQUIREMENTS

Experimental demands on the data management subsystem, the rf subsystem, and the ground network are presented below.

5.4.1 Data Management Subsystems Group

The requirements derived from the Mission Development Plan are divided into two major data management system functions. The first is the data collection and storage function mechanized in the baseline system by the data acquisition, data adapter, and data recording systems for electrical information and the facsimile and file systems for certain hard-copy data. The second major classification is the central data processing and computing function implemented in the baseline system by the IBM Saturn V computer. The above separation is observed in the outline of the following paragraphs.

5.4.1.1 Data Collection and Storage Requirements

As indicated previously, the definitive instrumentation data necessary to a rigorous derivation of data management system requirements are not available. However, available information presents some details of 16 experiments (principally the oceanographic measurements and the meteorological experiments) indicated in Table 5-2. While this information does not provide a comprehensive insight into the data storage loads and the time-line demands on the MORL data acquisition systems, it is useful for indicating gross limits of the data collection and storage requirements.

These experiments were obtained from the Applications Plan (Task II Report). Specifically, they were the design evaluation and approval tests to be performed on the candidate instruments required for the oceanographic/ meteorologic oriented Application Plan. As such, these task requirements do not completely test the capabilities of the data management system to respond to the Experiment Plan (Task II Report) requirements. However, a representative set of requirements was thus obtained and examined. This type of analysis, which was similar to the SCS analyses of Section 5.3, provided a better cross-section of experiment requirements than would have been obtained by restricting the analyses to experiments in the Experiment Plan.

Table 5-2 (page 1 of 4)

METEOROLOGICAL EXPERIMENT INSTRUMENTATION

Item	Parameter	Device	Channels	Duty Cycle (min. /orbit)	Rate (sample/sec each channel)	Word Length (bits)	Sample/Orbit Each Channel
1.	Atmospheric humidity	Dual channel IR radiometer	3	30 dayside	20 each	5	108×10^3
2.	Thermal radiation	IR spectrometer	1	Continuous	150	10	810×10^3
3.	Thermal radiation	IR spectrometer	1	Continuous	20	10	810×10^3
4.	Atmospheric temperature	Angular scanning IR radiometer	1	40 dayside	300	9	720×10^3
5.	Atmospheric pressure	Angular scanning IR radiometer		40 dayside	75	10	180×10^3
6.	Atmospheric temperature	IR interferometer or multislit grating IR radiometer		40 dayside or night	300	10	720×10^3
7.	Atmospheric humidity	IR interferometer or multislit grating IR radiometer	10	40 dayside or night	35	5	84×10^3
8.	Ozone	IR interferometer or multislit grating IR radiometer		40 dayside or night	20	5	48×10^3
9.	Cloud type	High resolution scanning IR radiometer		40 night	35	Picture	84×10^3

Table 5-2 (page 2 of 4)

Item	Parameter	Device	Channels	Duty Cycle (min/orbit)	Rate (sample/sec each channel)	Word Length (bits)	Sample/Orbit Each Channel
10.	Cloud pattern	High resolution scanning IR radiometer	1	40 night	2,400		5.76×10^6
11.	Cloud pattern	High resolution scanning IR radiometer		40 night	200×10^3		480×10^6
12.	Cloud top temperature	Narrow band IR radiometer	1	40 dayside	2,400	9	5.76×10^6
13.	Height of clouds	Narrow band IR radiometer	1		2,400	4	
14.	Thermal radiation	Wide band IR radiometer		40 dayside or night	300	10	720×10^3
15.	Surface temperature	Micro wave radiometer		40 dayside	300	9	720×10^3
16.	Atmospheric humidity	Multi channel microwave radiometer	4	Continuous	20	5	543×10^3
17.	Atmospheric temperature	Angular scanning μwave radiometer		40 dayside	300	9	720×10^3
18.	Atmospheric pressure	Angular scanning μwave radiometer	1	40 dayside	75	10	180×10^3
19.	Precipitation	Angular scanning μwave radiometer		40 dayside	75	4	180×10^3

Table 5-2 (page 3 of 4)

Item	Parameter	Device	Channels	Duty Cycle (min/orbit)	Rate (sample/sec each channel)	Word Length (bits)	Sample/Orbit Each Channel
20.	Height of cloud tops	Dual channel visible radiometer		40 dayside	2, 400	4	17.3×10^6
21.	Solar back-scatter radiation	Wide band visible radiometer		40 dayside	150	10	360×10^3
22.	Ozone	Dual channel U V radiometer	2	10 sunset	20	5	24×10
23.	Ozone	UV spectrometer	4	40 dayside	20	5	192×10^3
24.	Height of clouds	Dual channel TV system		30 pair of pictures, day	Video picture		7.5×10^6
25.	Cloud types	High resolution TV system		100 pictures, day	Video picture		4×10^8
26.	Cloud pattern	High resolution TV system	1	100 pictures, day	Video picture		
27.	Cloud coverage	High resolution TV system		100 pictures, day	Video picture		4.8×10^3
28.	Phase of cloud hydrometers	Polarimeter	4	20 dayside	4	7	4.8×10^3
29.	Atmospheric temperature	Dual star tracker		40 dayside or night	10	5	4.8×10^3

Table 5-2 (page 4 of 4)

Item	Parameter	Device	Channels	Duty Cycle (min/orbit)	Rate (sample/sec each channel)	Word Length (bits)	Sample/Orbit Each Channel
30.	Atmospheric pressure	Dual star tracker		40 dayside or night	0-1, 050 Kpars	10	4.8×10^3
31.	Height of cloud tops	Pulsed search-light and detector	3	40 night	2, 400	4	8.64×10^6
32.	Atmospheric pressure	Pulsed search-light and detector			75	10	
33.	Height of cloud	LIDAR	3	40 night	2, 400	4	8.64×10^6
34.	Atmospheric pressure	LIDAR pulsed laser			75	10	
35.	Wind	Radar	3		1 pps + data	6	7.2×10^3
36.	Precipitation	Radar	2	40 dayside or night	50 pps + 200 points/pulse	4	12.9×10^8
37.	Cloud type	IR camera			As required		
38.	Cloud pattern	IR camera					
39.	Cloud coverage	IR camera					
40.	Electrical discharges	Directional spherics receiver		Continuous	2/min.		180

If all meteorological measurements listed in Table 5-2 were to be made simultaneously, the total storage capacity required for measurements taken during a single orbit would be approximately 54×10^8 bits. Obviously, this is an excessive requirement. However, the instrument list (Table 5-2, left column) indicates many redundancies. It is, therefore, more logical to consider the meteorological package as a group of subexperiments, each embracing three to four measurements. This has been done to permit the establishment of realistic requirements in the absence of a time-line analysis of the experiment package.

The cloud cover measurements, items 9 through 13, appear to represent a worst-case instrument group. The maximum per orbit storage requirements represented by this group is 84×10^3 frames of video data and 50.4×10^6 bits of PCM. The 2.4×10^3 words/sec sample rate of the cloud-top temperature measurement establishes the upper bound for the PCM multiplexer frequency requirement among the meteorlogical instruments. The nine-bit cloud top temperature word is among the longest of the digital words necessary to preserve the desired accuracies of the meteorological experiment parameters. Further reduction of the instrument data presented in Table 5-2 indicates the following distribution:

1.	Word length:	50% consisting of 6 bits 50% consisting of 10 bits
2.	Sample Rates:	50% at 1.75 samples/sec 50% at 0.1 - 2.4K samples/sec
3.	Storage:	30% at 40-500 K bits per orbit 30% at 1-8 M bits per orbit 20% at 35-70 M bits per orbit 20% at video data.

In addition, the attitude of almost every one of the instruments listed in Table 5-2 must be adjusted relative to some known coordinate reference, such as MORL coordinates, inertial space, and so forth. This necessitates at least 3 command signals to each of the 40 instruments and an echo reply to each command, for a total of 240 additional signals that must be stored with the sensed data. The accuracy of these signals, and therefore the bits per word required to quantize the signals, must correspond to the accuracy and resolution requirements of the sensed data. Another annotation that must be stored with the measured variables include date and time, laboratory position, measurement number or series, and so on.

Information developed as part of the 48-hour time line accommodation study (Book II of this report) indicate the following distributions:

1. Word Length: 50% consisting of 1-10 bits
   50% consisting of 11-18 bits
2. Sample Rate: 30% at 1 sample/sec
   69% at 1-25 sample/sec
   1% at 1K sample/sec
3. Storage: 50% consisting of 3K bits/orbit
   50% consisting of 0.7-3M bits/orbit

This analysis provides the following general characteristics upon which the baseline data acquisition and storage system responsiveness assessment can be based:

1. Word lengths required for sensor output quantization are fairly evenly distributed over a range between 4 and 20 bits per word.
2. Data point sample rates, necessary to preserve the desired resolution of the sensors, range uniformly from 1 sample per minute to 25,000 samples per sec.
3. The upper and lower storage capacity limits, imposed by the sensors listed, are 3 kilobits and 75 megabits per orbit, respectively. The total storage requirement is the product of this single orbit memory requirement multiplied by the number of orbits of occultation.

In addition to the requirements for electrical information handling, both the oceanographic and meteorological experiments impose severe requirements for hardcopy experimental data storage. An estimate of the quantity of photographs which can accumulate can be based on the meteorological experiments. Items 37 through 39 (Table 5-2) require an infrared camera. Assuming a duty cycle of 40 min. per orbit, indicated for other such measurements (for example, Items 9 through 13, Table 5-2), and a conservative sample rate of approximately one photograph every 10 min. during the dayside measurement period, as many as 60 to 100 frames can accumulate during a single occultation period for this one measurement alone. If this data is to be hard-copied to the ground, the number of photographs requiring storage could reach 1,500 within a resupply period (90 days) if the experiment is conducted over the entire resupply period. A cursory review of the additional experiments of the Experiment Plan indicate a number of experiments which involve the generation of various types of hard-copy data (for example 2032, 2038, 2041, 2147, 2151, 2153, and 2154). Hence, the quantities derived above are quite conservative.

From Table 5-2 it can be concluded that much of the instrumentation will require assembly, disassembly, and extravehicular installation. This will necessitate a considerable amount of briefing and library homework on the part of the crew and, therefore, will affect the file and viewer subsystem, and probably the up-link facsimile function. Moreover, if the amount and type of instrumentation indicated for these measurement areas can be regarded as indicative of that which can be expected in the other experiments, it is probable that the on-board file and up-link facsimile subsystem requirements considered adequate for the baseline configuration will be exceeded considerably by the Experiment Plan. This observation also applies to the amount and type of stored hard-copy information, up-link instruction, and the skill types as well as skill levels of the crew. Since the magnitude of the problem is entirely subjective at this time, no specific requirement definition is possible.

5.4.1.2 Central Data Processing Requirements

The responsiveness of the computer is measured in terms of the following:

1. Memory capacity.
2. Computational speed.

The requirements for each of the above are determined by the functions to be performed by the computer, which include the following:

1. Sensor Control--Certain sensors require an on/off type of command, while others such as radiometers, cameras, and telescopes, need to be positioned to a point in space relative to the MORL-centered coordinate systems. The coordinate transformations can

be done either by analog or digital means, but for a large number of sensors (10 or more) the central computer approach would probably save a significant amount of hardware.

2. Data Sampling--This is more of a data acquisition function than a computer function. The computer, however, would be expected to provide programmed control or selection of some of the sensors to be interrogated.
3. Telemetry Storage Forecasting--Any translation of data formats, for instance, telemetry code, would be done by the computer.
4. Housekeeping--Normal checks on power supplies, air pressure, inventory, and so forth.
5. Orbit Navigation--Solution of the equations of MORL orbital motion, the equations containing simplified expansions of the gravitational, and drag models.
6. Rendezvous, Docking--Computation required as backup in rendezvous and docking of the logistics craft with MORL.
7. Simulated Exercises--Rendezvous, re-entry, and docking simulated exercises to maintain proficiency of the crew in these areas.
8. Experiment Data Processing--Data processing associated with the reduction, correlation, and analysis of experimental data.

The computational storage and rate requirements established in Phase II-A for the above functions are shown in Tables 5-3 and 5-4, respectively. The requirements associated with Items 1 through 7, which essentially can be considered operational functions, compare with similar requirements from such programs as Titan, Gemini, OAO, and Saturn, and, therefore, are reasonably representative.

It is concluded that it would be inappropriate to attempt to hypothesize data processing requirements for the experiments considered in this study for the following reasons:

1. The level of the experiment definition is not sufficient to facilitate the derivation requirements of the individual experiment to any acceptable degree of confidence.
2. The degree to which data processing for the various experiments should or must be done on board is not defined.
3. The extreme sensitivity of processing requirements to coincident processing needs indicates the necessity for experiment time-line specification, which is not available.

Table 5-3

PHASE II-A COMPUTATIONAL STORAGE REQUIREMENTS

(Equivalent 13-Bit Instruction Words)

Item	Function	Permanent	Temporary	Auxiliary Memory
1	Navigation	700*		700
	(rendezvous)			2, 750
2	Monitor	2, 400		2, 400
3	Checkout		3, 000	47, 600
4	Simulation		750	750
5	Executive routine	425*		425
6	Computational subroutines	1, 175*		1, 175
7	Insert/display	1, 000		1, 100
8	Diagnostic	750		750
9	Tape routine	350*		350
10	Communications	300		300
11	Experiments		450	20, 000**
	(concurrent)		4, 400	
	Total	9, 850	8, 600	78, 300

* Stored redundantly (double number shown)
** Total for experiements

Table 5-4

PHASE II-A COMPUTATIONAL RATE

Item	Function	Rate Basis	Estimated Add-Type Operations per Min.
1.	Navigation	One program iteration/min.	3, 450
2.	Monitor	200 signal/min.	2, 400
3.	Exp. B2	Function generation at 10/sec	72, 000
4.	Exp. J2	Two program iterations/min.	120, 000
5.	Input/output	I-O maximum rates	
	DCS	5.7 words/sec	3, 750
	DAS	40 words/sec	19, 200
	Insert/display	2 characters/sec	9, 850
	Typewriter	15.5 characters/sec	1, 080
	Tape	500 words/sec for maximum of 10 sec	55, 000
	Total		286, 730 Ops. /min.
			or 4, 780 Ops. /sec.
			+ 4, 780 Recommended for growth
			9, 560 Ops. /sec

5.4.2 RF Subsystems Group

There is a problem in determining the impact of the experiments on the RF subsystems because, to a large extent, these influences are filtered by the data management subsystems group. For instance, although a high volume of stored PCM data is indicated in Section 5.4.1, the PCM load problem can not directly affect the telemetry transmission subsystem because the playback rate of the tape recorders is only 76.8 kilobits per sec (Kbps). Similar considerations apply to the identified requirement for recorded voice and recorded video. However, if the baseline data management group is to be modified to meet the new requirements, the extent and/or nature of the modifications must be considered in conjunction with the baseline RF subsystems capabilities. The following problem areas are identified:

1. Recorded Video--Recorded video can have only a 2.16 mc video bandwidth (baseline real-time video bandwidth) to be compatible with the radio bandwidth of the baseline video transmitter (10 mc). The video bandwidth is based on a video horizontal resolution equivalent to 375 TV lines (number of elements in a horizontal line, 500, divided by the aspect ratio, 4:3), 500 lines per frame, and a frame rate of 15 frames per sec. Although the frame rate may be sufficient for many experiments, the resolution certainly is not consistent with the requirements in some cases (for example, 1,000 lines per frame: Experiment 768 of the meteorological group).
2. Film Scanning--The baseline film scanner can accommodate negatives up to 9 by 9 in., which are the maximum dimensions indicated in the experiments considered (for example, Experiment 255 of oceanographic group). However, the resolution capability (2,048 lines/frame) falls far short of the indicated requirements (for example, 1,000 lines per mm or approximately 2.25 x 10^5 lines per frame). Additionally, no provision is made for storing the video information from the scanner system.
3. Recorded Voice--The previously identified requirement for a high bulk of recorded voice information would indicate the necessity for an analog channel of approximately 30 kc bandwidth. This is based on the assumption that the recorder playback rate is speeded up by a factor of 10 to ensure playback within dump opportunities and, thus, eliminate tape overflow. This channel could be handled by the telemetry transmission system if time-sharing with certain of the other T/M subcarriers (in other words, the two 76.8 kbps PCM, the 640 bps PCM, the 2.4 kbps PCM, and the 1.0 and 2.0 kcps analog channels) were permitted. System modifications would be required to facilitate time-sharing.

The following two other items are worthy of discussion:

1. Because of the complexity of the experiments, the necessary close coordination of widely separated crewmen, and the time and inconvenience related to moving from one section of MORL to another, the application of the closed-circuit television to other than behavioral assessment and extra-vehicular monitoring is deemed advisable. For instance, coupling the television monitor with an automated file system would greatly improve the utility of file data and allow simultaneous viewing of the data by widely separated crewmen. Resolution problems must be considered and additional monitors and cameras probably would be required.
2. Because of the long crew stay times in orbit. it may be beneficial to provide off-duty ground-to-MORL radio communications on a non-interference basis with the regular voice subsystem. This could readily be provided at minimal cost via a ham system.

5.4.3 Experimental Aspects of the Ground Network

Experiments impose the following three specific requirements on the ground network:

1. Navigation accuracy (tracking).
2. Telemetry dump time.
3. Command (up-link).

Navigation accuracy requirements imposed by various experiments are identified in Table 5-5.

The telemetry dump requirement is quite severe. In the absence of a comprehensive time-line of the experimental activities, it is not possible to identify the exact impact on the ground network. However, recognizing that the medium rate recorder can accommodate only 128 min. of recording (18.432×10^6 words, of which only 3.3792×10^6 words are available for experimental purposes), the data storage rate (8.3×10^6 words/orbit) associated with the cloud-cover measurements of the meteorological experiment group alone would require 32 min. of dump time approximately every 0.5 orbits. If a quasi-statistical approach is taken using the information given in Section 5.4.1.1, the result is as follows. The average of the weighted average storage rates for the oceanographic and meteorological experiment groups is 0.8×10^6 words/orbit. Therefore, 32 min. of dump time must be accommodated by the ground network approximately every 4.25 orbits.

For experimental purposes, sensor pointing angle commands, such as required by the oceanographic experiments, establish command opportunity requirements. However, the commands can and must be issued in conjunction with tracking. Therefore, if the network satisfies the tracking requirement, it also satisfies the command requirement.

5.5 EXPERIMENT ACCOMMODATION OF THE COMMUNICATION SYSTEM

5.5.1 Data Management Subsystem Group

In the foregoing sections the MORL baseline data management subsystems capabilities were stated briefly and the results of a system requirements analysis were presented. While the specific measurement areas considered by no means approach the total postulated in the Experiment Plan, they establish requirements that, in some areas, tax the baseline systems to the extent that their operation is, at best, marginal, and, in others, to an extent that is well beyond baseline system capabilities.

Table 5-6 shows that the baseline system fails to meet the requirements, represented by the experiments investigated, in all important areas of the Data Collection and Storage subsystem. This point is further illustrated in the channel-by-channel comparison of requirements versus capability of Table 5-7. Since no time-line analysis was available, the channel and storage requirements for the various sample rates indicated represent a simple summation of those listed in Table 5-2 and those drawn from the 48-hour study. The storage and routing of a considerable quantity of up-link DSC data imposes further burdens not included in the tabulation (Tables 5-6 and 5-7) on the data collection and storage subsystem.

Information presented in Tables 5-6 and 5-7 indicate the extent of the effect of the new requirements on the baseline data acquisition, tape recording, and data adapter systems. Less obvious are the effects of hard-copy handling and storage requirements of the experiment packages investigated. While little information is available for establishing firm requirements for hard-copy data handling, the oceanographic and meteorological measurement

Table 5-5

EXPERIMENT NAVIGATION REQUIREMENTS

Experiment Number*	Application** (A and/or B)	Approximate Position Accuracy Required (nmi)***
252	A/B	0.33
255	A/B	0.33
257	B	0.33
258	B	0.33
2,011	A	1 to 10
2,013	A	1 to 10
2,022	A	1 to 10
2,146	A	1 to 10
2,147	B	15
2,148	B	3
2,149	B	15
2,150	B	15
2,151	B	15
2,153	A	1 to 10
2,155	A	1 to 10
2,156	A	1 to 10
2,157	A	1 to 10
2,159	A	1 to 10

* Refer to Experiment Plan (Figure 3-2)

** A--for correlation of experiment data with position.

B--for determination of sensor pointing angles.

*** Requirements presented as equivalent spherical position accuracy.

Table 5-6

SUMMARY OF BASELINE DATA MANAGEMENT SUBSYSTEM CAPABILITIES AND NEW MISSION REQUIREMENTS

	Baseline System Capability	New Mission Requirements
Maximum sample rate	120 S/sec without cross-strapping	2.5 K S/sec
PCM storage	2.2×10^8 information bits	10.0×10^8 information bits
Video storage	None	84×10^3 frames
Audio storage	None	1 tape channel (minimum)
Hard-copy storage	None indicated	500 to 1,000 photographs

areas suggest a possible photograph storage problem. The total number of photographs which can accumulate over a 90-day resupply period can easily exceed 1,000. One thousand photographs would require about 4 cu ft of storage volume, and could be easily accommodated aboard the MORL. However, the return of this material aboard the Apollo command module may impose some problems.

5.5.2 Navigational Aspects of the Ground Network

The navigation accuracy requirements imposed by various experiments were identified in Table 5-5. It is seen that although the majority of the requirements are within the capability determined in Phase IIa (Reference 4) which was determined to be ±0.05 nmi. at the time of an orbital fix on a ground site. The error increases with time after the fix but is still within

0.33 nmi after one orbit; therefore the requirements of Table 5-5 can be satisfied by the baseline network for the 50° case. Time phasing of experiments to minimize the error growth owing to ephemeris prediction inaccuracies may offer a solution in some cases. Still greater requirements would necessitate either a more optimum tracking network (more sites, located approximately 45° apart along the orbit) or another navigation technique.

The dump time requirements (see Section 5.4.3) cannot be met by the baseline network for either the 50° mission or the 90° mission. The synchronous mission is unique in that it offers continuous contact time. Therefore, the navigation and dump requirements could be met from a time point of view.

5.6 SYSTEM MODIFICATIONS

5.6.1 Data Management Subsystems Group Modifications

Three principal approaches for the fulfillment of the experimental requirements are available, singly or in combination:

1. Requirements can be met by redefining the mission to remove excessive system demands.
2. The baseline system can be upgraded by the addition of hardware in some subsystems to expand system capabilities in the more critical areas.
3. An entirely new system can be designed.

Evaluation of these approaches and tradeoffs among them must be considered in light of the facility with which each approach can be pursued, in other words, dollar cost and technological risk, and the consequences of each on total system capabilities.

5.6.1.1 Mission Redefinition and Mission Compromise

Many of the experiments now defined for MORL could be redesigned to enable the baseline system to support the experiments at the cost of only a minor compromise in the experimental goals. For example, it is possible to relax the requirements imposed on some of the instruments in the

Table 5-7

BASELINE COLLECTION AND STORAGE CAPABILITY VERSUS REQUIREMENTS (PER CHANNEL BASIS)

Sample Rate (samples/second)	Channels		Storage (bits/orbit)	
	Required	Baseline	Required	Baseline
1/60	35	95	Not Available	9.8×10^4
1/6	N. I.	41	N. I.	4.3×10^5
1	14	46	73.6×10^3	2.8×10^6
5	31	13	70.7×10^6	3.9×10^6
10	6	None	6.0×10^4	None
20	15	None	0.9×10^6	None
25	25	None	7.5×10^4	None
35	10	None	8.4×10^6	None
40	N. I.	11	N. I.	3.3×10^6
75	5	None	0.5×10^6	None
120	N. I.	None	N. I.	None
150	4	None	1.3×10^9	None
300	5	None	3.6×10^6	None
1×10^3	1	None	2.6×10^6	None
2.4×10^3	4	None	1.4×10^7	None

meteorological measurement package, replace them with other less demanding instruments, or omit some entirely without completely negating the purpose of the experiment.

However, it appears that this approach is not worthwhile since the baseline system cannot accommodate the requirements of Table 5-5 and 5-6. These requirements cannot be significantly relaxed without compromising their experimental goals.

5.6.1.2 Baseline System Upgrading

The major baseline system areas requiring modification are the following:

1. The hard-copy data handling function mechanized by the file and facsimile systems.
2. The data acquisition and data adapter systems.
3. The central data processing system.

It has been shown that the parameters dictating the extent of the file and facsimile systems are insufficiently well defined to permit these systems to be sized at this time. However, an important capability that could be incorporated into an upgraded or reconfigured file and facsimile system can be identified. This is to be able, at any remote console, to call up centrally stored hard-copy and to have it displayed automatically at the console.

While the data acquisition system configured in Phases I and IIa allowed for a growth contingency beyond the then defined telemetry requirements, no provision was made, other than limited cross strapping, for sample rates in excess of 120 per sec, or word lengths greater than six-bits in magnitude. Clearly (Table 5-6), these limits have been exceeded. Moreover, the simple provision of additional multiplexers (an 8 by 8 switching matrix) and doubling or tripling the basic clock frequency is not sufficient to meet the increased data sampling load either in terms of total sensors sampled or sample frequency. In short, the capability increases required, as determined by these analyses, are beyond those which can be attained by simply adding to or enlarging the present system.

5.6.1.3 System Redesign

A basic ground rule of the previous MORL studies required that the data management subsystem group be configured on the basis of current technology or off-the-shelf hardware. Technological advances since Phase IIa,

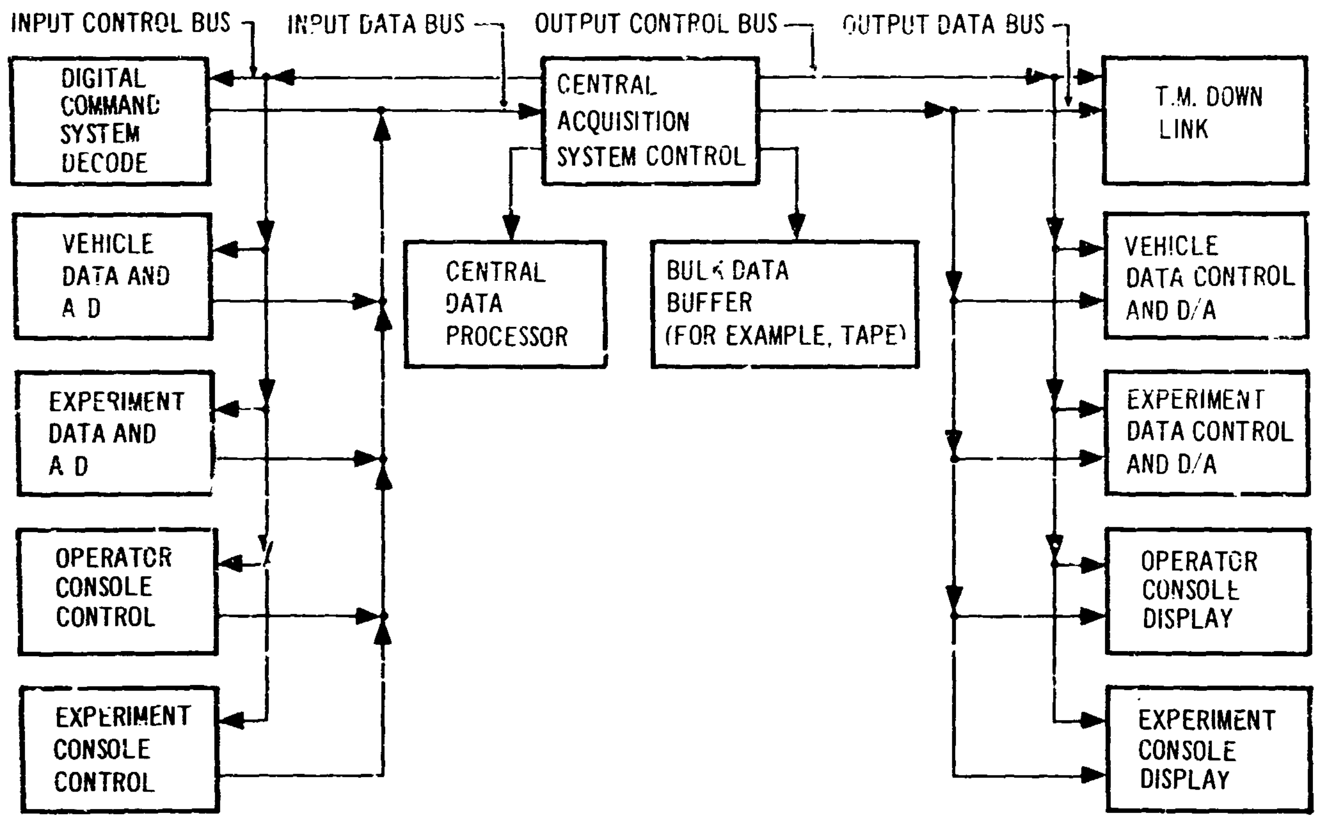


Figure 5-4. MORL Communication and Telemetry System – Alternate Configuration

primarily in microcircuitry, make possible a system concept, illustrated in Figure 5-4, that could overcome some of the baseline system problems previously specified or implied.

The basis for this concept is the fact that information collecting and formatting is common to all communications and data management functions. It is, therefore, proposed that all subsystem groups share a single, common information collection and exchange unit central to the communication and data management system. The central programmable data acquisition unit provides all necessary multiplexers and buffer registers. Local analog-digital/digital-analog conversion, with an all-digital internal data distribution system, is proposed instead of central, time-shared conversion. This is justified by projected developments in micro-integrated analog-digital converters.

The baseline MORL system assumed that operational data rates would be relatively low and would require continuous monitoring while experimental information rates would be higher and sampled on an intermittent command basis. The data acquisition system that resulted used a triple channel concept, with Low, Medium, and High rate channels. Separation of the data channels on a speed basis alone appears to impose severe cost penalties in unnecessary duplication of hardware. However, some justification exists for considering separate channels for continuous and intermittent data. Again, advanced technology, in this case, improved multiplexing techniques, higher speed central encoders or local (signal source) conversion, and higher buffer memory (tape unit) speeds suggest the possibility of a single telemetry data acquisition channel of sufficient bandwidth to facilitate the continuous monitoring of those information sources requiring it, as well as permitting interruptions to accommodate intermittent data without exceeding tolerable truncation error limits.

A single channel telemetry input can become attractive in the light of the probable need to increase the down-link PCM bit rate to accommodate the high volume of PCM data previously indicated. Items limiting this bit rate are, of course, the telemetry transmitter itself, (for instance, bandwidth) and the buffer memory read speed. Both areas require re-examination. Of course, all subfunctions mechanized in the baseline system must be re-appraised with a view to improving their mechanization by incorporation of advanced techniques. The data management system is singled out because of its broad system impact. An expanded computer capability will open the possibility of on-board experimental data reduction and an improved data compaction capability that would, of course, affect the entire telemetry and data acquisition system design. Table 5-8 indicates current computer technology, as well as technology for the 1970 to 1975 time period.

In summary, the design review of the data management subsystems group has suggested that the effectiveness of the following items be evaluated with a view toward increasing the data management system capacity:

1. Single programmable data acquisition and distribution function central to all other subfunctions.

Table 5-8

COMPARATIVE COMPUTER TECHNOLOGY

Computer	Add (μsec)	Multiply (μsec)	Divide (μsec)	Thousand* (ops/sec)	Double Precision	Weight (lb)	Power (watts)	Volume (cu ft)
Current technology	7-12	24-92	35-128	100	No	35	160	.5
1970 to 1972	1	10	10-20	815	Optional	20-40	100	.35
Baseline computer	84	336	672	12.2	No	77	131	2.2

* Defined as 80% add, subtract, etc. (short instructions)
15% multiply
5% divide (long instructions)

2. An all-digital data distribution bus with local (signal source) analog-digital conversion.
3. A single data channel telemetry function with interrupt capability.
4. On-board operational and experimental data reduction function.

In summary a general purpose system, meeting the specifications of Table 5-9 is called for.

A preliminary market survey indicates that the parameters specified in Table 5-9 are readily attainable applying a 1970 technology projection.

5.6.2 RF Subsystem Group Changes

No changes to the baseline RF subsystems group are proposed, beyond those previously discussed, for the following two reasons:

1. The gain margins for the various subsystems are satisfactory for the 50° and 90° inclination missions.
2. Any modifications to the RF subsystems group to enhance responsiveness must be predicted on changes deemed necessary for the data management group and the ground network as indicated previously. Therefore, the exact nature of the modifications must be held in abeyance until total systems re-optimization is performed.

Use of the unified RF carrier philosophy should be considered for MORL. The relative ease associated with time-sharing of bandwidth renders this concept much more flexible than the baseline system and, therefore, fundamentally more responsive to a wide range of requirements.

5.6.3 Ground Network

From the previous discussions it can be seen that the baseline network is only marginally adequate for telemetry and, in some instances, for tracking as well.

Table 5-9

NECESSARY DATA MANAGEMENT SYSTEMS SPECIFICATIONS

Item	Specification
1.	Continuous transmission system confidence checking.
2.	Automatic and manual routing of data--512 sources and destinations.
3.	Variable sample rate: $2.0 \times 10^{3} \geq$ data point samples per second $\geq 10^{-5}$ $0.5 \times 10^{-3} \leq$ data point sample period, seconds $\leq 10^{5}$ (10^{5} sec 1 day)
4.	Variable sample word length: $4 \leq$ data sample magnitude bits per word ≤ 16
5.	Variable data point reporting rate: (manually alterable) every 10^{n} sample (n = 0, 1, 2, 3.)
6.	Variable on-board quick-look monitoring: (manually alterable) every 10^{n} sample, (n = 0, 1, 2, 3.)
7.	Multiple stored multiplexing and formatting programs 4 programs with automatic and manual branching from program to program
8.	Total of 512 addressable, rack-mounted data points Information accessed at data point addressed is a function of equipment mounted in rack
9.	Variable memory word format Programmer may use 16 different word formats for packing the differing data word lengths so that all memory bit positions contain meaningful information
10.	Four interrupt levels--memory interleave.

Several expanded networks have been investigated as indicated previously. Table 5-10 indicates the various duty-cycle parameters for each network with the baseline values included for comparison (50 inclination mission). Hawaii appears as a logical addition to the baseline network, in that it has a low maximum occultation period and a sufficient average contact time per day at least for low-rate recording. It affords a relatively high number of successive tracking opportunities that should improve the maximum and average navigation accuracy situation. Additionally, Hawaii is located approximately 80° (longitude) from Cape Kennedy which is near optimum (90°) for ephemeris error reduction based on tracking by two sites. As was pointed out earlier, Guaymas must be added in addition to Hawaii to afford sufficient coverage for the 90° inclination mission. However, for either mission, the network modification above is not the only solution for the high telemetry loads; the telemetry recording system and the RF telemetry link also contribute to the problem, and the resolution must consider a compromise between all three factors.

5.7 CONFIGURATION/STRUCTURE SYSTEM

The configuration and structure design of MORL was reviewed in the light of the Experiment Plan requirements. The following changes are recommended to fully accommodate the experiment requirements:

1. A new console and operator control panel should be installed in the hangar section.
2. The laboratory scientific console should be enlarged.
3. A thermally controlled structural frame must be designed to accommodate those experiments having tight pointing requirements.

5.7.1 Configuration Analysis

The requirements of each experiment listed in the Experiment Plan were reviewed to determine the major equipments needed, where the experiment would be conducted aboard MORL, and what limitations MORL imposed upon the experiment. This information is presented in Table 5-11. As shown in this table, most of the experiments can be accomplished without changing the configuration or the experiment itself.

Table 5-10

DUTY CYCLE FACTORS FOR EXPANDED GROUND NETWORKS

Network	Average Usable Contact Time Per Day (minutes)	Average Occultation Period (Orbits)	Maximum Occultation Period (Orbits)	Average Number of Successive Orbit Contacts (Orbits)	Average Contact Duration (minutes)
Cape Kennedy Corpus Christi Hawaii	66	3	4	8	5.54
Cape Kennedy Corpus Christi Guaymas	57	5	9	5	5.13
Cape Kennedy Corpus Christi Guaymas Hawaii	80	4	4	10	5.55
Baseline: Cape Kennedy Corpus Christi	43	6	9	3	5.67

5.7.1.1 Hangar Deck

The hangar deck console is necessary since certain of the equipment operating in the airlock will require close control not suitable from the more remote position at the scientific console on the operations deck. The console should be capable of having the standard laboratory measurement apparatus mounted interchangeably with the scientific console for efficient use of the equipment. In addition, it should be capable of rapid and simple exchange of unique experiment equipment, such as control and data panels associated with single experiments. The console must be sufficiently large for one operator; it is desirable for it to be large enough for two operators for greater flexibility and simultaneous operation of two or more experiments. The sizing should be similar to the consoles in the operations deck, and the MORL dimensional setup will be satisfactory.

The pointing and tracking telescope (PTS) is used in conjunction with numerous other experiments, some of which are located in the airlock. These experiments prevent the installation of the PTS in that location. Nevertheless, the PTS should be near the experiment airlock and should be mounted in such a way that it may point in the same direction as the earth-centered experiment sensors. Mounting alignment with the attitude reference system is also necessary.

5.7.1.2 Operations Deck

The MORL scientific console is actually in two parts, one part contains the maintenance and laboratory troubleshooting apparatus, and the other is used for setup and operation of experiments. The latter is a one-man operators console. The work load on a single test conductor for multiple sensor experimentation such as IR, microwave radiometry, and the radar experiments is quite high because three experiments must be controlled simultaneously during the short time duration the target is available (approximately 10 min. over any given target). Therefore, additional scientific console space is necessary to allow two or more operators to work simultaneously during peak experimental loads. The hangar deck console may be used for some of these requirements, but additional console volume at the scientific work station is necessary.

Table 5-11

EQUIPMENT, LOCATION, AND LIMITATIONS (page 1 of 23)

Exp. No.	Experiment Title	Major Lab Equipment and Experiment Location	Laboratory Responsiveness (Fully Resp. Unless Otherwise Noted)
2001	Evaluation of EC/LS System	1. Samples from water, hygiene, air, and galley 2. Preparation and incubation in biological room 3. Analysis at analytical station	
2002	Ionization-Radiation Measurement	1. Measurements from equipment on boom 2. Experiment airlock for equipment transfer 3. Control and data from scientific console	
20031 thru 20038	Long Term Zero G Effects on Crewman 1 through 9	1. Biomed console for tests 2. Analytical station for analysis 3. Biological room for sample preparation	
20041 thru 20048	Evaluation of Conditioning Devices and Techniques. Crewman 1 through 9	1. Biomedical/behavioral station 2. Centrifuge 3. Living quarters (exercise equipment)	
2005	Toxicological Studies of Respiratory Gas	1. Analytical station	

Table 5-11 (page 2 of 23)

Exp. No.	Experiment Title	Major Lab Equipment and Experiment Location	Laboratory Responsiveness (Fully Resp. Unless Otherwise Noted)
20051 thru 20069	Behavioral Responses in Orbital Environment. Crewman 1 through 9 (Part I)	1. Measurements and data at behavioral console	
20071 thru 20079	Crew Performance in Orbital and Re-entry Operations. Crewman 1 through 9	1. Measurements and data at behavioral console	
20081 thru 20089	Behavioral Responses in Orbital Environment. Crewman 1 through 9 (Part II)	1. Measurements and data at behavioral console	
20091 thru 20099	Retention of Skills. Crewman 1 through 9	1. Measurements and data at behavioral console	
2010	Meteoroid Physical Characteristics	1. Equipment located on circumferential masts 2. Mast control and data recording from experiment console	
2011	Measurement Laboratory Local Exterior Environment	1. Equipment mounted on articulating boom 2. Experiment airlock for equipment transfer 3. Control and data from experiment console	

Table 5-11 (page 3 of 23)

Exp. No.	Experiment Title	Major Lab Equipment and Experiment Location	Laboratory Responsiveness (Fully Resp. Unless Otherwise Noted)
2012	Activation Measurement of Materials	1. Test samples mounted throughout interior 2. Analysis at analytical station	
2013	Atmospheric Drag Measurements	1. Drag specimens prepared in hangar 2. Experiment mounted on articulating boom via experiment airlock 3. Control and data from scientific console	
2014	Measurement of Noise, Vibration, etc.	1. Vibration pickups mounted at selected point in interior 2. Vibration and [illegible] analyzer equipment at scientific bay	
2015	Ventilation of Respired Gases in Manned Space Enclosure	1. Analytical and data equipment at analytical station	
2016	Function and Disfunction of Gravity Sensitive Organ in Zero G	1. Test equipment and samples located in biological room 2. Analytical and data equipment in biological room	
2017	Changes in Vestib. Nerve Activity and Vestib. --Mebry at Zero and Small G loads	1. Equipment and sample (monkey) located in Animal cargo module along side MORL	Laboratory is fully responsive provided animal cargo module is assumed part of laboratory system

Table 5-11 (page 4 of 23)

Exp. No.	Experiment Title	Major Lab Equipment and Experiment Location	Laboratory Responsiveness (Fully Resp. Unless Otherwise Noted)
2017 (cont)		2. Animal life support equipment and analytical/data equipment are located in and are part of animal module	
20181 thru 20189	Plasticity in Human Sensorimotor Control--Crewmen 1 through 9	1. Behavioral console 2. Behavioral chair 3. Data and measurement apparatus at behavioral console	
20191 thru 20198	Evoked Electromyography in Zero G--Crewmen 1 through 9 Except 4	1. Equipment and measurements at behavioral console 2. Data at behavioral console	
2020	Effects of Zero G on Embryological Development Processes	1. Equipment and samples located in biological room 2. Analytical equipment located in biological room	
2021	Effects of Zero G on the Flour Beetle	1. Equipment and samples located in biological room 2. Analytical and support equipment located in biological room	

Table 5-11 (page 5 of 23)

Exp. No.	Experiment Title	Major Lab Equipment and Experiment Location	Laboratory Responsiveness (Fully Resp. Unless Otherwise Noted)
2022	Effects of Space Environment on Bacteria	1. Samples exposed via experiment airlock 2. Space Radiation telescope on boom 3. Analysis and growth equipment in biological room	
2023	Functional and Morphological Responses to the Space Environment of Rodents	1. Animal life support equipment (rats) and analytical/data apparatus are located in and part of animal cargo module	Laboratory is fully responsive provided animal cargo module is assumed part of lab system
2024	Effect of Zero G on Immune Defenses Against Pathogenic Agents	1. Same as 2023 (mice)	Same as 2023
2025	Effect of Zero G on Dividing Human cells in Culture	1. Samples and equipment located in biological room 2. Analytical, data, and measurement apparatus in biological room	
2026	Plant Studies in the Orbital Environment	1. Samples and equipment located in biological room 2. Analytical, data and measurement apparatus in biological room	

Table 5-11 (page 6 of 23)

Exp. No.	Experiment Title	Major Lab Equipment and Experiment Location	Laboratory Responsiveness (Fully Resp. Unless Otherwise Noted)
2027	Analysis of Animal Adjustment in Degrees of Weightlessness	1. Same as 2023 (mice)	Same as 2023
2028	Ballistocardiograph and Vibrocardiograph Evaluation	1. Equipment and data/measurement apparatus located at behavioral station	
2029	Gravity Gradient and Techniques --Development Tests	1. Test craft deployed on articulated boom 2. Experiment mounted on boom via experiment airlock 3. Optical measurements made from interior	
2030	Evaluation of Low Range (10^{-8} to 10^{-11}G) Accelerometers	1. Test equipment located at scientific bay 2. Data and analysis equipment located at scientific bay	
2031	Evaluation of Oxygen Recovery System	1. Test equipment located in hangar 2. Data and analysis equipment located at hangar console	Hangar work bench and console are necessary
2032	Evaluation of Electro Optical Techniques and Equipment	1. Test equipment located in experiment airlock 2. Data, analysis and control at hangar console 3. Film processing in biological room	Hangar console required

Table 5-11 (page 7 of 23)

Exp. No.	Experiment Title	Major Lab Equipment and Experiment Location	Laboratory Responsiveness (Fully Resp. Unless Otherwise Noted)
2033	Control System Evaluation--Internal Components SCS Evaluation	1. Evaluation of lab equipment 2. Tests and analysis from scientific console	
2034	Reaction Control Components	1. Test craft deployed on articulating boom 2. Experiment mounted on boom via experiment airlock 3. Other equipment located in hangar 4. Test control from scientific and operational consoles	
2035	SCS Evaluation--Stability	1. Evaluation of lab equipment 2. Control and data from scientific operational consoles	
2036	Radioisotope-Thermo-Electric Power System Integration	1. Equipment located in aft compartment 2. Experiment control and data from scientific console	
2037	Effects of Hi Energy Particulate Radiation on Organic Living and Nonliving Materials	1. Equipment located externally 2. Analysis and data at scientific console	
2038	Measurement of Solar Absorptivity and Thermal Emissivity of Materials	1. Samples and test equipment located externally 2. Analysis conducted at analytical station and scientific console	

Table 5-11 (page 8 of 23)

Exp. No.	Experiment Title	Major Lab Equipment and Experiment Location	Laboratory Responsiveness (Fully Resp. Unless Otherwise Noted)
2039	Effects of Space Environment on Materials and Surfaces	1. Samples located externally 2. Analysis conducted at analytical static and scientific console	
2C40	Meteoroid Penetrating of Materials and Surface Reflectivity Measurement	1. Same as 2938 and 2039	
2041	Measurement of Jet Flow in Vacuum	1. Equipment located both near RCS engine and in experiment airlock 2. Measurement and analytic equipment in scientific and console	Hangar console required
2042	Cold Welding of Materials in Space	1. Test samples and equipment located externally 2. Control and data analysis from scientific console	
2043	Evaluation of Self-Sealing Structures	1. Test samples exposed to space externally 2. Test conducted in experiment airlock 3. Test control and data at hangar console	Hangar console required

Table 5-11 (page 9 of 23)

Exp. No.	Experiment Title	Major Lab Equipment and Experiment Location	Laboratory Responsiveness (Fully Resp. Unless Otherwise Noted)
2044	Fatigue Test of Materials After Exposure and Space Environment	1. Same as 2043	Hangar console required
2045	Crystallization Studies	1. Test and Equipment located in biological room 2. Data and analysis at analytical station	
2046	Effects of Atmosphere and Materials on Laser Operation	1. Equipment located in experiment airlock 2. Control and data from hangar console	1. Hangar console required 2. Precise alignment of equipment required
2140	Effect of Space Environment on Daphinia Pulex	1. Equipment, samples, data, and analysis located in biological room	
2141	Discrimination and Communication of Animals in Zero G	1. Equipment and test located in animal module	Laboratory is fully responsive provided animal cargo module is assumed part of lab system
2142	Photosynthetic Action Spectra During Exposure of Algae to Spaceflight	1. Samples and equipment located either in biological room or animal cargo module 2. Analysis and data in biological room	
2143	Changes in Offspring Conceived, Developed and Born in Zero G	1. Same as 2033 (mice)	Same as 2023

Table 5-11 (page 10 of 23)

Exp. No.	Experiment Title	Major Lab Equipment and Experiment Location	Laboratory Responsiveness (Fully Resp. Unless Otherwise Noted)
2144	Origin of Biochemical Compounds	1. Equipment located in experiment airlock 2. Analysis at analytical station	
2145	Effects of Orbital Environment on Cerebral, Neuronal and Glial Chemistry	1. Same as 2033 (rats)	Same as 2023
2146	Cosmic Dust Measurements	1. Equipment located on 4 circumferential masts 2. Experiment control and data from scientific console	
2147	Large Aperture Telescope Evaluation	1. Requires telescope cargo module 2. Film processing in biological laboratory	Lab is responsive provided telescope cargo module assumed to be part of the laboratory system
2148	Space Radiation Telescope Evaluation	1. Equipment located on articulating boom 2. Experiment airlock required 3. Control of boom and experiment from scientific console	
2149	Extraterrestrial Electromagnetic Radiation Survey, Part I	1. Equipment located externally on aft end of vehicle 2. Experiment control from scientific console	

Table 5-11 (page 11 of 23)

Exp. No.	Experiment Title	Major Lab Equipment and Experiment Location	Laboratory Responsiveness (Fully Resp. Unless Otherwise Noted)
2150	Extraterrestrial Electromagnetic Radiation Survey, Part II	1. Same as 2149	
2151	Spectral Analysis of Star Sources Useful for Space Navigation	1. Requires telescope module same as 2147	Same as 2147
2152	Solar Corona and Solar Flare Observation	1. Equipment located externally on sensor beam 2. Experiment control from scientific console	Precise alignment required
2153	Artificial Meteor Observation	1. Equipment located in experiment airlock 2. Hangar deck console for control and data management	Hangar deck console required
2154	Observation of Ionized Cloud in Space	1. Same as 2147	Same as 2147
2155	High Energy Particle Physics using Nuclear Emulsions	1. Samples located externally 2. Photo processing and storage in biological room	
2156	High Energy Particle Physics using Spark Chamber	1. Equipment located in hangar 2. Data and control at hangar console	Hangar console required
2157	Planetary and Satellite Surface Properties	1. Equipment located at scientific work bench	

Table 5-11 (page 12 of 23)

Exp. No.	Experiment Title	Major Lab Equipment and Experiment Location	Laboratory Responsiveness (Fully Resp. Unless Otherwise Noted)
2158	Measurement of Nongravitational Forces	1. Equipment located and deployed from hangar 2. Experiment control and data management from scientific console	
2159	Particle Injection Study	1. Equipment located in experiment airlock 2. Pointing and tracking telescope required 3. Experiment control from hangar console	1. Hangar console required 2. Pointing and tracking telescope required
2160	Auroral Survey	1. Equipment located in experiment airlock 2. Control from hangar console	Hangar console required
2161	Methods to Obtain Local Ultra-High Vacuum	1. Equipment located on articulating boom 2. Experiment airlock used for deployment 3. Control and data from scientific console	
1	Lubrication, Bearings	1. Equipment located externally and internally 2 Control and data management from scientific console 3. Analysis at analytical console	

Table 5-11 (page 13 of 23)

Exp. No.	Experiment Title	Major Lab Equipment and Experiment Location	Laboratory Responsiveness (Fully Resp. Unless Otherwise Noted)
201	Assembly and Repair-Antenna	1. External installation 2. No data management or experiment control	
202	Boresight and Alignment--Antenna	1. External installation on integrated sensor structure 2. Optical boresight from hangar	1. Machined and integrated sensor structure required 2. Means for optical boresighting required
3	Antenna Dynamics	1. External installation on integrated sensor structure 2. Optical measurements from hangar 3. Ground/spacecraft communication from scientific console	1. Same as 202
4	Plastic Materials UV Sensitivity	1. Same as 2037	
5	Special Tools	1. Evaluated throughout Lab interior and exterior	
6	Particle Impingement--Optics	1. All optical devices evaluated 2. Experiment airlock used 3. Optical element evaluation at analytical console	

Table 5-11 (page 14 of 23)

Exp. No.	Experiment Title	Major Lab Equipment and Experiment Location	Laboratory Responsiveness (Fully Resp. Unless Otherwise Noted)
71	Assembly, Repair and Lube--External Optics	1. External installation of equipment 2. Repair at scientific and analytical consoles	
72	Boresight and Alignment--Optics	1. Same as 202	1. Same as 202
15	Film Stability	1. Film storage--radiation secure and temperature controlled 2. Film processing in biological room 3. Analysis at analytical station	
16	Picture Resolution	1. Analytical console	
18	Assembly, Repair, Lube, and Boresight Alignment Methods--Radiometer (IR and microwave)	1. Same as 202 2. Internal assembly and repair from hangar and scientific bay	1. Same as 202
228	Tracking Capability	1. Pointing and tracking telescope 2. Hangar and hangar console	1. PTS required 2. Hangar console required
229	Lock-on Procedure-V/H Meter	1. External installation of antenna 2. Evaluation, analysis, and data management at scientific console	

Table 5-11 (page 15 of 23)

Exp. No.	Experiment Title	Major Lab Equipment and Experiment Location	Laboratory Responsiveness (Fully Resp. Unless Otherwise Noted)
230	Operational Capability--V/H Meter	1. Same as 229	
231	Tracking Capability--V/H Meter	1. Same as 229 plus use of PTS	1. PTS required
232	Performance Evaluation of Radar Profilometer	1. Same as 229	
233	Lock-on Procedure--Radar Profilometer	1. Same as 229	
234	Camera test	1. Equipment installed in experiment airlock 2. Operation and data management at hangar console 3. Film processing at biological room 4. Analysis at analytical console	1. Hangar console required 2. Optical alignment with attitude reference system (ARS) required
235	Image Motion Compensation--Camera	1. Same as 234 plus: 2. PTS used with camera 3. ARS, IMC, and camera interface required	1. Hangar console required 2. PTS required 3. Optical alignment with ARS required
236	Integration Test--Microwave	1. External equipment on integrated structure	1. Aligned, integrated structure

Table 5-11 (page 16 of 23)

Exp. No.	Experiment Title	Major Lab Equipment and Experiment Location	Laboratory Responsiveness (Fully Resp. Unless Otherwise Noted)
236 (Cont)		2. Test operation and data management from scientific console 3. Boresight alignment from hangar	2. Means for optical boresight of antenna required
237	Absolute Accuracy--Microwave Radiometer	1. Same as 236	
239	IR Radiometer--Operational Tests	1. Same as 236	1. Same as 236
242	Polarimeter/Transponder Satellite System	1. Same as 236	1. Same as 236
243	Alignment and Lock-on S-Band Polarimeter	1. Same as 236	1. Same as 236
244	Auto and Manual Tracking--Transponder Satellite	1. PTS required for manual tracking 2. Antenna-directional for auto tracking 3. Controllable auxiliary satellite 4. Experiment control at scientific console 5. Satellite launched from boom 6. Experiment preparation in hangar	1. PTS required

Table 5-11 (page 17 of 23)

Exp. No.	Experiment Title	Major Lab Equipment and Experiment Location	Laboratory Responsiveness (Fully Resp. Unless Otherwise Noted)
246	Integration Test-Laser System	1. Same as 234	Same as 234
247	Align and Lock-on Laser	1. Same as 234	Same as 234
248	Manual and Auto Tracking--Transponder Antenna	1. Same as 244	Same as 244
252	Performance Evaluation--Radar	1. Same as 229	
253	Performance Evaluation of V/H Meter	1. Same as 229	
254	Performance Evaluation of Radar Profilometer	1. Same as 229	
21	Stability of Radiometer (IR and Microwave) in Space Environment	1. Same as 236	Same as 236
23	Bandwidth and Characteristics of Filters	1. Same as 234	Same as 234
25	Absolute Accuracy of IR Radiometer	1. Same as 236	Same as 236
31	Environmental Effects on Transponder Satellite	1. Satellite inspection 2. Component evaluation--scientific and analysis consoles	

Table 5-11 (page 18 of 23)

Exp. No.	Experiment Title	Major Lab Equipment and Experiment Location	Laboratory Responsiveness (Fully Resp. Unless Otherwise Noted)
36	Boresight and Alignment--Laser	1. Same as 234	Same as 234
38	Baseline Determination--Laser Satellite	1. Same as 40	
40	Ejection and Retrieval Recovery Orientation and Stability of Transponder Satellite	1. Controllable auxiliary satellite (CAS) control antenna--exterior 2. CAS launched from articulating boom 3. Experiment airlock 4. Satellite control from scientific console 5. CAS preparation in hangar	
226	Performance Evaluation K&C Bond Radar	1. Same as 229	
227	Radar Lock-on Procedure	1. Same as 229	
255	Performance Evaluation of Camera	1. Same as 234	Same as 234
256	Performance Evaluation of Microwave Radiometer	1. Same as 236	Same as 236
257	Performance Evaluation of IR Radiometer	1. Same as 236	Same as 236

Table 5-11 (page 19 of 23)

Exp. No.	Experiment Title	Major Lab Equipment and Experiment Location	Laboratory Responsiveness (Fully Resp. Unless Otherwise Noted)
249	Performance Evaluation of S-Band Polarimeter	1. Same as 229	
260	Performance Evaluation of LIDAR	1. Same as 234	
501	IR and UV Detector--Space Effects	1. All IR and UV equipment evaluation after exposure 2. Scientific and analytical console required 3. Operational space effects controlled from scientific console	
502	Microwave Radiometer Window--Space Effects	1. Same as 236	Same as 236
504	Internal Bearings	1. Same as 1	
510	Large Mirrors--Environment	1. Same as 6	
521	Star Tracker Sensor	1. Integrated structural beam 2. Optical alignment on installation 3. Physical accessibility to star tracker	Integrated Structural Sensor Structure required
523	Dual Star Tracker-Gyro Stability	1. Same as 521	
524	TV Detector--Space Effects	1. Same as 501	

Table 5-11 (page 20 of 23)

Exp. No.	Experiment Title	Major Lab Equipment and Experiment Location	Laboratory Responsiveness (Fully Resp. Unless Otherwise Noted)
601	IR Detector Characteristics--Cooling	1. Same as 236 or 234	Same as 236 or 234
603	PMT Characteristics--Radiometer	1. Same as 236	
604	Lube of Gimbals, Bearing--Zoom	1. Same as 1	
608	EVA--Optical Elements	1. Crew airlock and experiment airlock required 2. Equipment mounted on integrated structure	
613	Photo Multiplier Tube (Searchlight)	1. Same as 236	
614	Assy, Boresight--Mirrors (Searchlight)	1. Same as 202	Same as 202
615	Discharge Tube Specification (Searchlight)	1. Same as 202 and 236	
616	Mirror and Laser Mount and Alignment	1. Same as 202 and 246	
617	LIDAR Functional Evaluation	1. Same as 234	
619	Visible Detectors--Characteristics and Cooling	1. Same as 234 or 236	

Table 5-11 (page 21 of 23)

Exp. No.	Experiment Title	Major Lab Equipment and Experiment Location	Laboratory Responsiveness (Fully Resp. Unless Otherwise Noted)
623	Microwave Radiometer Performance	1. Same as 229	
634	Radar Test and Procedures	1. Same as 236	
639	Dual Storage Tracker	1. Same as 523	
640	Assy of Star Tracker EVA	1. Same as 521	
657	Characteristics of TV Detectors	1. Same as 234 or 236	
659	Zoom Lens Characteristics	1. Same as 234	
673	Directional Sferics Receiver	1. Same as 236	
700	Wide Band Visual Radiometer	1. Same as 619 (234 or 236)	
703	Dual Channel Visible Radiometer	1. Same as 700 (234 or 236)	
704	IR Spectrometer	1. Equipment installed in experiment airlock 2. Control and data management from hangar console	Hangar console required
705	Dual Channel UV Radiometer	1. Same as 236	Same as 236
710	Polarimeter (Visible)	1. Same as 619 (234 or 236)	
711	UV Spectrometer	1. Same as 704	

Table 5-11 (page 22 of 23)

Exp. No.	Experiment Title	Major Lab Equipment and Experiment Location	Laboratory Responsiveness (Fully Resp. Unless Otherwise Noted)
713	Dual Star Tracker	1. Same as 521	Same as 521
716	IR Interferometer and IR Spectrometer	1. Same as 704	
718	TV System	1. Same as 657 (234 or 236)	
719	IR Camera	1. Same as 234	
721	Dual Channel TV	1. Same as 657 (234 or 236)	
723	Directional Sferics Receiver	1. Same as 673 (236)	
753	Dual Channel Visible Radiometer	1. Same as 700 (234 or 236)	
754	IR Spectrometer	1. Same as 704	Same as 704
758	Visible Radiometer (Wideband)	1. Same as 700	
760	Polarimeter (Visible)	1. Same as 710 (234 or 236)	
761	UV Spectrometer	1. Same as 711 (704)	
763	Dual Star Tracker	1. Same as 713 (521)	

Table 5-11 (page 23 of 23)

Exp. No.	Experiment Title	Major Lab Equipment and Experiment Location	Laboratory Responsiveness (Fully Resp. Unless Otherwise Noted)
766	IR Interferometer, IR Spectrometer	1. Same as 716 (704)	
768	TV System	1. Same as 718 (234 or 236)	
769	IR Camera	1. Same as 719 (234)	
771	Dual Channel TV	1. Same as 721 (234 or 236)	
773	Directional Sferics Receiver	1. Same as 673 (236)	

5.7.2 Structure Analysis

The basic structural system of the laboratory is adequate to meet the requirements of the experimental program. Certain experiments will undoubtedly require attachments, deployment means, feedthroughs, or thermal control which are not provided by the basic structure. These are thought to be minor modifications that can be solved by the detailed experiment/structure designs and do not lead to structural problems.

The single modification of the laboratory structure system is made necessary by a series of experiments which require installation of sensors with extremely precise directional requirements. The sensor positional and angular tolerance must be maintained not only with respect to the vehicle attitude reference system but also with respect to other sensors during all phases of the flight regime. The detailed requirements of the integrated sensor structure are noted in Book II of this report; the prime requirements are extreme rigidity, dimensional stability under the space thermal environment, high accuracy with respect to the vehicle attitude reference system (ARS), vernier adjustment of the sensor mountings, and means for optical check of sensor/ARS alignment. Although the actual vehicle structure may not be required to meet the sensor installation capability outlined above, the structural system must permit such auxiliary structure to be installed; therefore, modification to the basic vehicle structure will be necessary to support those experiments which have the noted installation restrictions. The following two approaches are recommended:

1. Install a thermally controlled integrated structural frame to the vehicle exterior following launch and orbit injection.
2. Install the thermally controlled structural frame inside the vehicle with means of opening doors or removing panels to reveal the sensors to the space environment.

Both approaches will be evaluated in Task IV of this study.

Section 6
RADIATION ANALYSIS

Space vehicles are subjected to a radiation environment composed of charged particles from galactic cosmic rays, trapped radiation belts, solar flares, as well as neutrons and gamma rays from on-board nuclear sources. These radiations may constitute a major hazard to crew members; therefore, the shield weight required to reduce the corresponding radiobiological dose to an acceptable value may be a significant factor in the vehicle design. The radiation shield analyses conducted in Phase IIa indicated that large shield weights were required for some missions and also that considerable uncertainties were present in these analyses. The Phase IIb radiation analyses were conducted in an attempt to reduce these uncertainties and to improve the overall shield weight requirements by judicious placement of the shield materials. To accomplish this, a shield optimization program, Shield Weight Optimization for Radiobiological Dose (SWORD), was developed with Douglas IRAD funds. This computer program was subsequently used under the MORL contract, in conjunction with other analyses, to establish updated shielding requirements.

The mission requirements imposed on the MORL by the Task II analysis could be satisfied by operating in a 50° or 90° inclination orbit at a 200-nmi altitude or a synchronous orbit at a 19,350-nmi altitude and a 28.3° inclination. The radiation environment at these three orbit conditions was determined and the shield weights required to reduce the radiation flux to acceptable dose levels were calculated. The results of this analysis show that, with the environment described and the dose criteria specified, the MORL can accommodate the 50° low-altitude mission by adding only 165 lb of shielding material to the top dome of the laboratory. This shield would probably be provided by increasing the effective thickness of this aluminum structure by 0.02 in. The resultant shielding would provide adequate

PRECEDING PAGE BLANK NOT FILMED.

protection for a 1-year mission, including the dose delivered by 2 major solar flare events.

The polar mission at 200-nmi altitude was analyzed and found to require 1,820 lb of shielding material to provide adequate protection for an average crew stay time of 6 months. This shield could be implemented by adding 0.21, 0.39, and 0.06 in. of polyethylene to the laboratory bottom, sides, and dome top, respectively. The shield could also be affected by increasing the aluminum structure thickness sufficiently to add the same weight of material at the above locations. The thickness of aluminum required would be about one third that of polyethylene because of the density difference. These shield weight requirements could be reduced to only 330 lb by incorporating a biowell to provide protection against the occurrence of the intermittent solar flares. However, at this time the use of the biowell would not be recommended because the payload capability of the Saturn V launch vehicle payload for this mission is large enough to permit weight increases to gain operational flexibility and convenience.

The synchronous mission was also examined and, on the basis of the present analysis, was found to require excessive radiation shielding; therefore, the MORL should not be committed to the synchronous mission until further studies are completed. When the nominal value of electron flux at this altitude was used, the required shield weight was found to be in excess of 20 tons. Further, because of an uncertainty in the order of magnitude of the electron flux at this altitude, the resultant potential variation in shield weight requirements is currently from 4,400 lb to 110,000 lb. The large nominal weight requirement, when added to the weight of the basic MORL is beyond the capability of the Saturn V laboratory launch vehicle. Even if the shield is delivered by logistics vehicles, the addition of shielding material, 10 in. or more thick, to the laboratory walls seems out of the question.

The nominal shield weight required (40,000 lb) represents a significant increase over the requirements previously reported. This increase is the result of a number of improvements in the analytical method. The dose received increased from the Phase IIa calculations as shown on the following page.

	Item	Increase Factor
1.	Change in the normalization of incident electron spectrum.	1.4
2.	Improved low-energy bremsstrahlung flux to dose conversion factors.	3.0
3.	Modification to electron transmission calculations.	1.1
4.	Corrections to bremsstrahlung dose buildup formulation.	2-5

The net result of these increases is shown in the dose attenuation curves of Figure 6-1. The relationship between the dose received by a man-model as a function of the area density of shield material is shown from the Phase IIa and the present analysis. An all-aluminum shield was assumed for comparison purposes. The shield density (gm/cm^2) is proportional to the total shield weight and shield distribution for a given configuration. Thus, it can be seen from Figure 6-1 that there are significant relative differences in the shield material required to attenuate the flux to a given dose level.

The conclusion is that the present MORL concept cannot be confidently committed to the synchronous mission until further analyses are completed. These analyses must define the magnitude of the radiation environment at synchronous altitude and must also determine the feasibility of incorporating large shield weights in the MORL designs. Specifically, the following areas of study are recommended: (1) determine the minimum volume that must be shielded and that can still accommodate the mission requirements; (2) study the effectiveness of using on-board materials, such as water and propellant, as inherent radiation shielding; (3) evaluate the effectiveness of personal portable shields; (4) study the use of laminated shields, including the means by which they would be resupplied and installed in orbit; (5) critically evaluate the possibility of relaxing the allowable dose criteria; and (6) define the electron flux levels at the synchronous altitude.

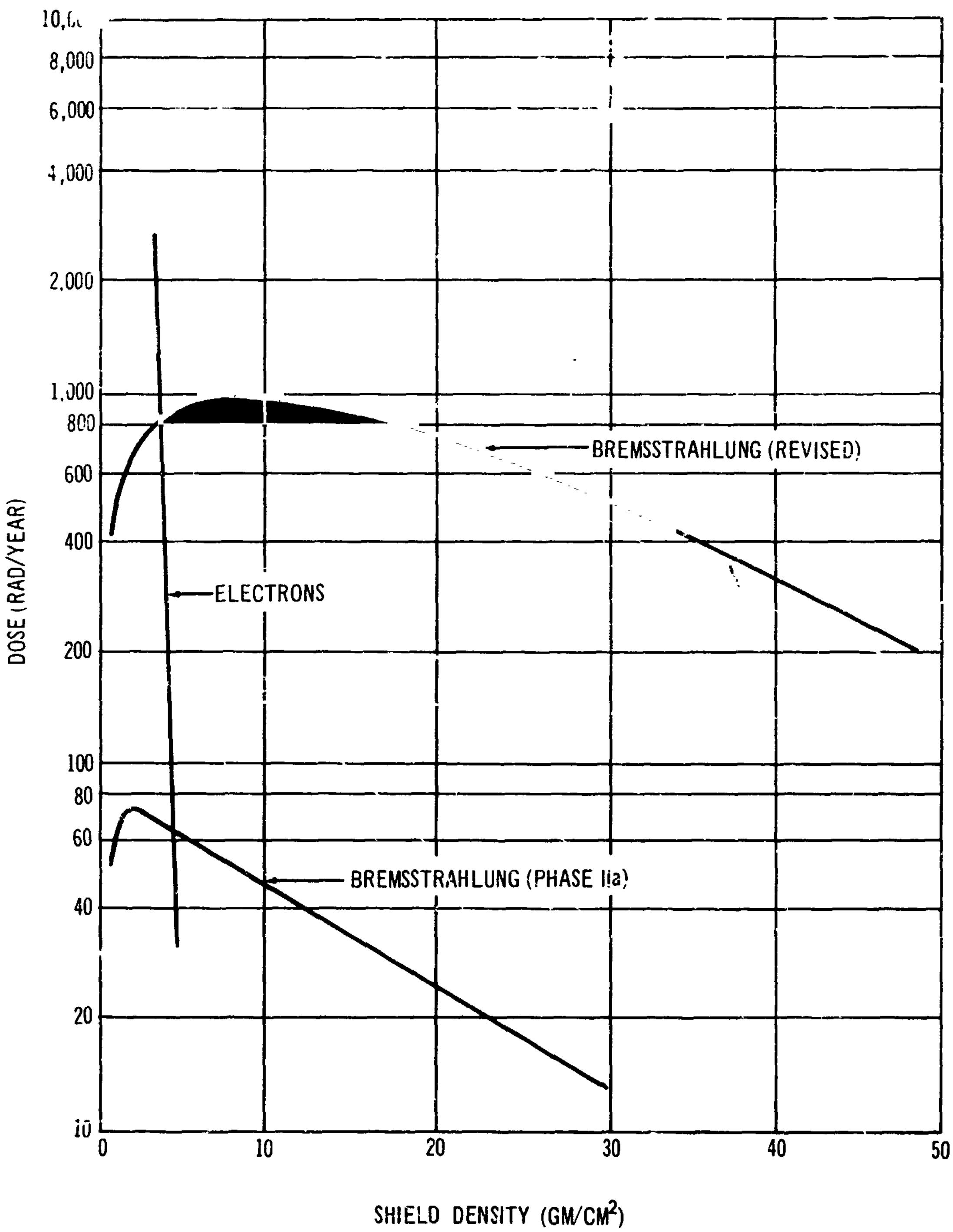


Figure 6-1. Comparison of Bremsstrahlung Radiation Dose

6.1 RADIATION SOURCES AND UNCERTAINTIES

Radiation shielding analyses included the effects of several radiation sources contributing to biological dose levels:

1. Potential On-Board Sources--Neutron and gamma radiations from an isotope power system.
2. Space Radiation Sources--Protons from a model solar flare, geomagnetically trapped protons, geomagnetically trapped natural and artificial electrons, and electron bremsstrahlung.

6.1.1 Potential On-Board Source

Originally, the objective of the Task III analyses was limited to assessing the responsiveness of the MORL configuration developed and defined at the end of the Phase IIa study. This baseline configuration does not include significant on-board nuclear sources. However, consideration is being given to changing the solar panel electrical system to an isotope/Brayton-cycle power system. To present a comprehensive radiation analysis of the MORL which will continue to remain valid even if the power system change is made, the Task III radiation analyses deviated from the original study objective by anticipating the change.

The geometric and material characteristics of an isotope/Brayton-cycle power system were included in the quadric-surface geometric descriptions of the MORL vehicle. Neutron and gamma ray fluxes within occupied regions of the vehicle, resulting from radiation leakage from the fuel block, were computed by integrating point-to-point attenuation kernels over the source volume. The neutron and gamma source strengths represent the maximum values attained over the design operating lifetime, assuming an initial power level of 43.2kWt (11 kWe). Neutron attenuation through source, shield, and vehicle materials was computed within SWORD by a modified Albert-Welton kernel; gamma attenuation was computed by a five-energy-group exponential kernel with build-up corrections. The SWORD capability to compute single scattered fluxes was not used on production computations since scattered fluxes were initially found to be negligible.

6.1.2 Space Radiation Environment

The space radiation to which the MORL is exposed is a combined result of the orbital motion of the vehicle and the local radiation characteristics of regions of space traversed by the MORL.

To account for the effect of the MORL passing through locally varying radiation environments, a computer program called OGRE was used to determine an average radiation environment for each orbit to be studied. In essence, OGRE integrates, point-by-point over the entire orbital path, the flux spectra valid only at local points. This integration results in an average flux spectrum representative of the average conditions to be encountered along the orbital path. Tables B-2 to B-6 in Appendix B represent the output of OGRE and the average radiation environment in the low altitude (200 nmi) and synchronous orbits. The effect of natural and artificial electrons, as well as the effect of solar flares, is included in this model.

The major uncertainty in the data of Tables B-2 to B-6 can be attributed to inadequate data on the decay of artificial (Starfish) electrons and on the magnitude of the trapped electron flux at high (synchronous) altitudes.

By agreement with NASA/LRC, it was assumed that Starfish electrons at 200-nmi altitudes will have decayed by the 1971 MORL launch date. However, for a complete analysis, calculations based on the following, more pessimistic model of Starfish electron decay were also performed.

In this model, artificial electron decay is assumed to be a strong function of atmospheric density. Thus, as atmospheric density varies with solar activity, electron decay rates also vary with solar activity. The following mechanism can be postulated to explain this phenomenon. The 11-year solar activity cycle causes periodic changes in the heat flux incident on the atmosphere, with consequent expansion and retraction of the atmosphere. Thus, as the solar cycle approaches its next maximum in 1968-1969, individual particles which make up the atmosphere are moved out and further away from earth. The net effect is a decrease in atmospheric density at low (50 to 60 nmi) altitudes and an increase at higher (200 nmi) altitudes. The higher atmospheric density will tend to sweep out artificial electrons at the MORL (200 nmi) altitude, but will not persist long enough to completely eliminate Starfish electrons. The solar cycle will once again approach a minimum (1974), and will cause the atmosphere to retreat toward Earth. Thus, once again upper-altitude air density will be too low to allow rapid clearing of artificial electrons. Of course, after a sufficiently large number of solar cycles, essentially all artificial electrons would be swept out.

The practical difference between the above views of artificial electron decay is that, in the first case, complete decay is assumed by 1971; in the second, only a decay to about 16% of the 1963 levels is assumed. Resulting flux spectra are given in Tables B-2 to B-6.

If artificial electrons are assumed to decay to negligible values, natural trapped electrons become the dominant electron radiation source at low altitudes. The intensity of the natural electron radiation source is known only within an order of magnitude. However, based on even the most conservative assumptions, shielding requirements were found to be dominated by the trapped proton and solar flare proton dose. Thus, the natural electron source uncertainty is not important.

The uncertainty in the trapped electron flux at high altitudes (synchronous orbit is a result of a lack of good data and the existence of sporadic short-term variations. These two factors prohibit specifying with confidence the high altitude electron flux to within less than plus or minus an order of magnitude. Thus, calculations for the synchronous missions were based on large parametric variations in assumed source intensities. The nominal electron flux used for the synchronous mission is presented in Table B-3. The basic dose versus shield thickness attenuation relationship is shown in Figure B-4. The trapped proton dose is not shown, since it is negligible at this altitude. Other pertinent dose attenuation characteristics for different missions and shield thicknesses are shown in Figure B-3 and B-5 to B-8.

All the dose attenuation data for trapped radiation are shown for an exposure of 1 year. To account for varying amounts of time crewmen spend in different areas of the MORL, these data were modified by suitable weighting factors derived from timeline analyses.

In addition to a careful study of the above source uncertainties, the current radiation analysis results differ from previous (Phase IIa, Phase IIb Interim Report) results in the following respects. A new electron-bremsstrahlung dose attenuation curve (Figure B-4) was constructed for the synchronous mission. The bremsstrahlung portion of the curve (that portion beyond a shield thickness of 4 gm/cm^2) is approximately an order of magnitude higher than that used in previous analyses. This change is the composite effect of the following modifications:

1. The differential energy spectrum of the incident electron radiation was changed and resulted in an increase in the total electron source which directly affected the amount of bremsstrahlung produced, since this secondary radiation is directly proportional to the electron source. The resulting effect was to increase the dose resulting from electron radiation by a factor of 1.4 over that used in the Phase IIa analysis.
2. The bremsstrahlung flux-to-dose conversion factors were modified principally in the low-energy (keV) region. These factors, which convert the radiation flux values to biological dose rate units at a detector point, were determined more exactly in the low energy region, resulting in an increase in the dose rate at the shield densities of interest by a factor of three.
3. The electron transmission calculations were slightly modified. These calculations deal with the number of electron penetrations of a given shield material. The effect of this change was to increase the bremsstrahlung dose contribution by a factor of 1.1 over that previously used.
4. The bremsstrahlung dose buildup formulations which account for the scattered component of the radiation were corrected. The effect was to flatten the curve for dose as a function of shield thickness in Figure B-4 in the first portion of the shield thickness. The resulting increase in dose received over that previously used in Phase IIa is from a factor of two to five, depending on the shield thickness considered.

It should be pointed out that the present state of the definition of the radiation environments and details of the analytic techniques by which these fluxes are attenuated through shields and converted to dose are to some extent continually changing. The four modifications described above are part of this process.

The next effect of these changes was an increase in MORL shield weight requirements. In view of the large uncertainties still remaining, some of which may cause further shield weight increases, the importance of obtaining further data is magnified. In particular, the following areas are of major concern:

1. The intensity and the spatial and energy distribution of trapped planetary electrons must be known with greater precision to allow determination of bremsstrahlung effects.
2. Improved data are required on the production and transmission of low-energy bremsstrahlung. At present, the effects of bremsstrahlung are predicted by the extrapolation of gamma ray buildup factors from higher energy ranges to the low-energy ranges of interest.

6.2 DOSE CRITERIA

The weight of radiation shielding required is highly dependent on the allowable dose criteria used. The dose criteria used in this analysis have been abstracted from Reference 11 and have been coordinated with NASA/LRC. The dose criteria in question are listed in Table 6-1.

Table 6-1

MAXIMUM ALLOWABLE DOSE (REM)

	Exposure in Months			
Critical Area	3	6	12	Single Exposure
Skin of whole body	300	350	400	100
Lens of eye	225	240	270	100
Bone marrow	50	80	100	25

6.3 MORL SHIELD ANALYSIS

The shielding analysis reported in this section consisted of a description of the configuration to be shielded, a description of dose points and locations, and the effect on these of the radiation environment specified in Section 6.2. The tool of analysis used was the SWORD program described in Appendix B.

6.3.1 System Geometric Description

The geometry description used in previous shielding analyses for MORL provided the basic vehicle model used in this study. Several additions and modifications to the original geometry were incorporated in order to represent the present vehicle configurations more precisely. The major additions involved an on-board nuclear source, a biowell, docked Apollos, multimission modules, and an additional man-model location. The basic laboratory configuration used is shown in Figures 6-2 and 6-3 for illustrative purposes. The numbers thereon refer to the various planes, spheres, cones, and cylinders which simulate the structural design. The various locations for shield material are indicated by the notation, t. Two configurations were used in the analysis, each identical except for the number of external appendages (stored Apollo, and so forth). The low-altitude configuration was described with 70 quadric surfaces and 89 homogenous material regions. The synchronous configuration was defined with 63 surfaces and 76 regions. The cylinder surrounding the entire configuration in Figure 6-2 was used to ease the calculation process only and does not represent any structure or shield weight. A detailed description of the vehicle interior, which included the relative locations and material densities of the major consoles and storage cabinets, was used. All other portions of the vehicles were described to the extent of including major bulkheads and pressure shells.

A number of candidate shield locations were established for use in SWORD optimization calculations. These potential shield locations designated t_1, t_2, and t_3, included the circular bottom surface of the laboratory area, the cylindrical side of the laboratory area and centrifuge, and the hemispherical top of the rest area respectively. For missions involving the biowell, five additional shield locations (t_4 through t_8) were specified. These were the top, bottom, and three sides of the biowell.

6.3.2 Dose Points

The mission integrated dose to crew members is dependent on their space-time positions within the crew compartment. This effect was approximated by defining three representative man-model locations and by establishing time weighting factors for each. One man-model was centrally located in

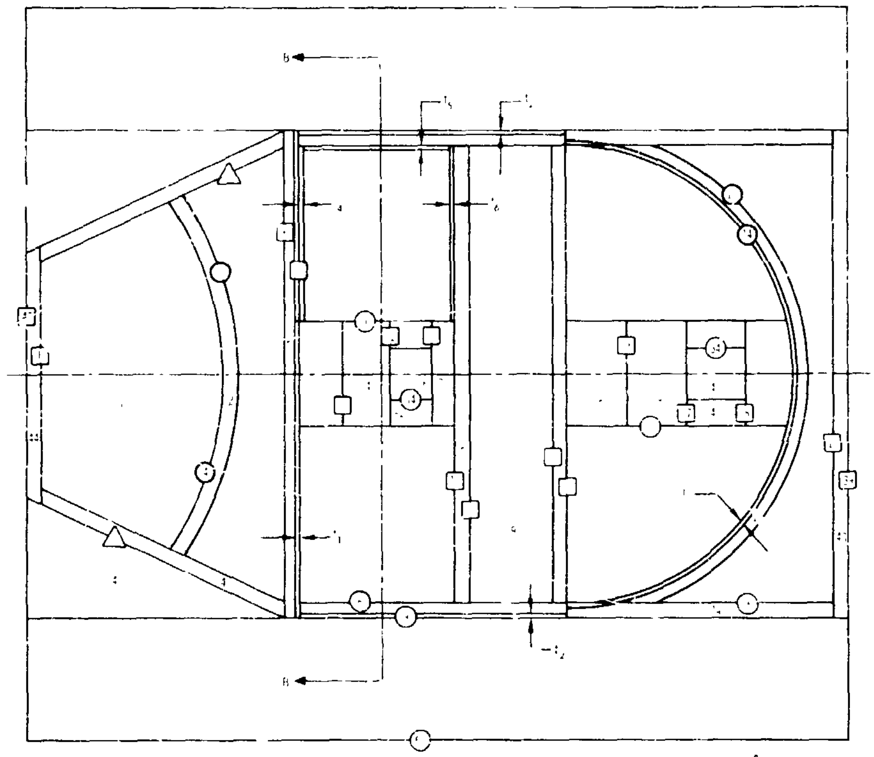


Figure 6-2. Identification of Surfaces and Regions Defining MORL Geometry

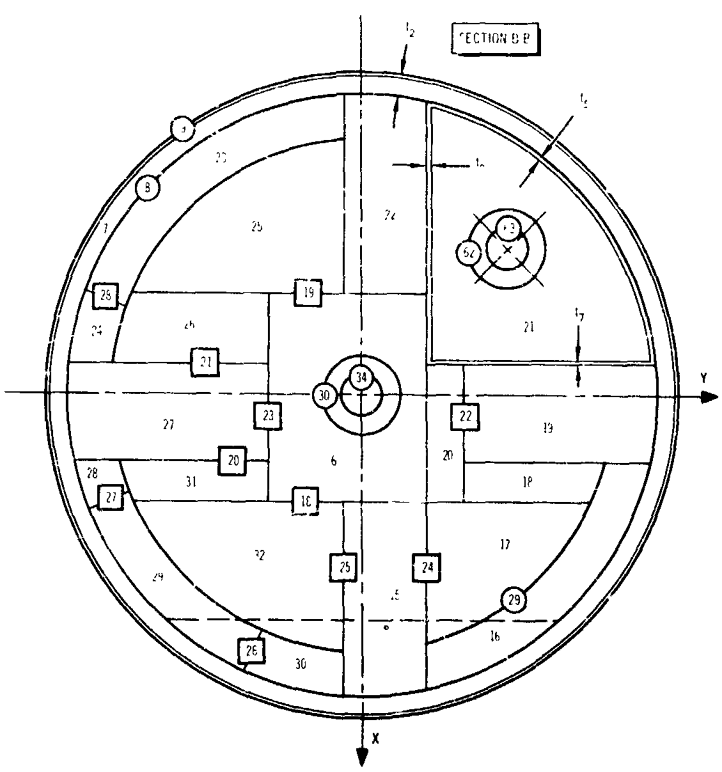


Figure 6-3. Cross-Section Through MORL Vehicle

the biowell area, the second in the center of the laboratory area, and the third in the center of the rest area. The weighting factors used in the shield optimization process are shown in Table 6-2. They account for the percent of time spent in each dose receptor location.

Table 6-2
TIME WEIGHTING FACTOR (%)

Location of Man-Model	Shielded Biowell		Unshielded Biowell	
	Trapped Radiation	Solar Flare	Trapped Radiation	Solar Flare
Biowell	15	100	15	43
Laboratory	20	0	20	57
Rest area	65	0	65	0

The percent of time spent in each area corresponds to the timeline history of a crewman aboard the MORL as determined by the experimental program. An attempt was made to determine an average weighting factor, since each crewman has quite different duty cycles. For those cases which incorporated a biowell, it was assumed that all of the dose received from a solar flare event was taken in the biowell area.

The man-model used for these analyses was the CARS model (Reference 12) with equal contained volumes. A cylindrical representation is shown in Figure 6-4.

Two cylinders are used, the top one representing the head and the lower one representing the trunk of the body. The anisotropic effects of the man-model geometries necessitated the treatment of more than one representative dose-point position on each. In general, these positions were chosen to give equal consideration to each potential shield location. The dose points were selected to be representative of the locations of radiation-sensitive areas of a man-model. The number of dose points used for each man-model location and critical organ are given in Table 6-3.

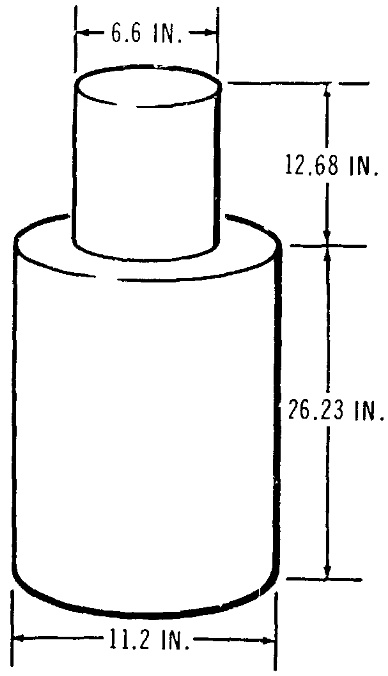


Figure 6-4. Man-Model Used in Shield Analyses

Table 6-3
NUMBER OF POINTS BY MAN-MODEL LOCATION

Critical Organ	Biowell	Laboratory	Rest	Total
Lens of eye	2	1	2	5
Skin	2	1	2	5
Blood forming organs	2	1	2	5

6.3.3 MORL Shield Analysis Results

The current MORL shield analyses are summarized in Table 6-4. The results are shown for each of the three missions of interest, with various combinations of the shield sensitive parameters. These parameters are defined as follows:

1. Mission Duration--Exposure duration (days).
2. Artificial Electrons--The presence or absence of the artificial electron belts radically affect the low-altitude shield weight requirements. No means the artificial electrons source was ignored.
3. Solar Cycle--Max. or min. pertains to the 11-year period activity cycle of the sun. Max. refers to the maximum solar activity, that is, 1968 to 1969.
4. Number of Solar Flares--The assumed numbers of flare events encountered while in orbit. For the cases with a biowell, the full flare dose was received in the biowell.
5. Biowell--The presence or absence of a specially shielded portion of the laboratory.
6. Total Shield Weight--The total weight of polyethylene shield material that must be added to the laboratory structure for adequate radiation protection.
7. Shield Thickness--The thickness of the segmented shield jacket that must be added to MORL.
   A. T_1--Laboratory floor.
   B. T_2--Laboratory cyclindrical sides.
   C. T_3--Hemispheric laboratory dome.
   D. T_4 through T_8--Position of the biowell. These segments are illustrated in Figures 6-2 and 6-3.
8. Absorbed Dose--The dose received (REM) by each organ is shown for the mission and shield thicknesses specified. Also shown are the amount received from the solar flare alone.

6.3.3.1 The Baseline 200-nmi Altitude, 50° Inclination Mission

The radiation analyses results listed in Table 6-4 show very small shield weight requirements for the 50° mission when the artificial electron flux was assumed to have decayed to a negligible value as discussed in Section 6.1. These results are shown in Case No. 1 through 12 of Table 6-4. A shield weight of only 165 lb will provide adequate protection for the crew for a

Table 6-4 (page 1 of 2)

MORL SHIELD REQUIREMENTS SUMMARY

Orbit Altitude and Inclination	Case No	Mission Duration (days)	Artif Elec-trons	Solar Cycle	No. of Solar Flares	Bio-Well	Total Shield Weight	Shield Thicknesses (In.) Main Shield T1	T2	T3	Biowell T4	T5	T6	T7	T8	Absorbed Dose (REM) Mission Total Eyes	Skin	BFO	Flare Total Eyes	Skin	BFO
200 nmi, 50°	1	90	no	min	1	no	110	0	0	0.04						97	117		4	55	
	2	180	no	min	1	no	110	0	0	0.04						147	176		43	55	
	3	365	no	min	1	no	110	0	0	0.04						247	294		43	55	
	4	180	no	min	2	no	110	0	0	0.04						193	238		87	109	
	5	365	no	min	2	no	165	0	0	0.06						202	216		86	109	
	6	365	no	min	2	yes	165	0	0	0.06	0	0	0	0	0	221	213		103	106	
	7	365	no	min	3	no	165	0	0	0.06						249	278		130	163	
	8	365	no	min	3	yes	275	0	0	0.06	0	0.27	0	0	0	226	210		122	107	
	9	90	no	max	1	no	55	0	0	0.02						118	263		44	55	
	10	180	no	max	1	no	110	0	0	0.04						78	88		43	55	
	11	365	no	max	1	no	110	0	0	0.04						108	118		43	55	
	12	365	no	max	2	no	110	[illegible]	0	0.04						155	177		87	109	
	13	90	yes	min	1	no	386		0	0.14						224	258	6	42	57	1
	14	180	yes	min	1	no	326	0	0	0.1						243	300	11	39	52	1
	15	365	yes	min	1	no	1,410	0	0.02	0.48						289	307	13	37	49	1
	16	180	yes	min	2	no	990	0	0	0.35						248	315	14	77	103	2
	17	365	yes	min	2	no	1,650	0	0.07	0.51						255	368	24	68	91	2
	18	365	yes	min	2	yes	1,490	0	0	0.47	0.12	0.45	0	0	0	284	349	22	60	57	2
	19	365	yes	min	3	no	1,900	0	0.12	0.54						286	370	76	96	128	3
	20	365	yes	min	3	yes	1,625	0	0	0.49	0.24	0.54	0.11	0	0	284	354	23	75	77	3
	21	90	yes	max	1	no	330	0	0	0.2						228	262	3	42	53	1
	22	180	yes	max	1	no	745	0	0	0.25						243	300	5	38	52	1
	23	365	yes	max	1	no	1,190	0	0	0.42						265	374	9	38	51	1
	24	365	yes	max	2	no	1,375	0	0.02	0.46						286	379	10	73	98	3
	25	90	no	min	1	no	1,820	0.19	0.39	0.07						106	111		89*	97*	
	26	180	no	min	1	no	1,820	0.21	0.39	0.06						123	125		89*	96*	
	27	180	no	min	2	no	1,790	0.21	0.39	0.05						213	222		179	193*	
	28	180	no	min	2	yes	330	0	0	0.03	0.12	0.53	0.21	0	0	213	223		182	191	

NOTE:
1. T1 through T8 are shield thickness defined in Figures 6-2 and 6-3.
2. BFO - dose received by the blood-forming organs

Blood-forming organs.

Table 6-4 (page 2 of 2)

Crewman	Run No.	Crew Skills: Mechanical/ Photo Technician	Mechanical Engineer/ Optics	Electrical Engineer/ Mechanical	Meteorologist	Oceanographer	Observer	General Worker	EC/LS Repair Specialist	RCS, SCS, Structure Repair Specialist	Communications/ Telemetry Repair Specialist
Flight Commander	1	X					X	X	X		
	2	X					X	X	X		
	3	X					X	X	X		
Deputy Flight Commander	1	X	X				X	X		X	
	2	X	X				X	X		X	
	3	X	X				X	X		X	
Operations Engineer	1			X			X	X			X
	2			X			X	X			X
	3	X		X			X	X			X
Medical Doctor	1						X	X			
	2						X	X			
	3						X	X			
Physical Scientist (1)	1					X	X	X			
	2					X	X	X			
	3					X	X	X			
Physical Scientist (2)	1				X		X	X			
	2				X		X	X			
	3					X	X	X			
Physical Scientist (3)	1				X		X	X			
	2				X		X	X			
	3					X	X	X			
Physical Scientist (4)	1					X	X	X			
	2					X	X	X			
	3					X	X	X			
Physical Scientist (5)	1				X		X	X			
	2				X		X	X			
	3				X		X	X			

period of 1 year, even if 2 major solar flare events are encountered. At this inclination, the effect of solar flare protons is small because of the shielding effect of the Earth's electromagnetic field. The 165 lb of shielding material is required only on the dome portion of the laboratory to a depth of 0.06 in. of polyethylene. Undoubtedly, for this case aluminum would be used for the shield material rather than polyethylene and the effective structure thickness increased by 0.02 in., since the density of aluminum is about 3 times that of polyethylene. The shield calculations were performed with polyethylene as the shield material. However, for protons the shielding characteristics of aluminum are similar, as shown in Reference 13, when they are compared on a density basis.

The shield weight mentioned above provides protection against two major solar flare events. The 12 November 1960 solar flare event was used as a model flare. Figure 6-5 shows the estimated probability of encountering n or more major solar flares as a function of mission duration. These curves are based on a Poisson probability distribution with an average rate of occurrence of one flare per year. This average rate of occurrence corresponds to that observed in the maximum activity portion of the 11-year solar cycle. At other portions of the solar cycle, this average rate of occurrence may be reduced.

The curves of Figure 6-5 show the probability of exceeding the dose limit when shielding is provided to attenuate the dose received from n-1 flares to an acceptable value. Thus, if protection is provided to safely absorb the dose from 2 (n-1) solar flares in 1 year, the probability of exceeding this dose criterion is only 0.08. Therefore, it would appear that protection for two solar flares for a 1-year mission is adequate.

The effect of the solar cycle activity is negligible for this mission, as can be seen by comparing Cases 3 and 11. Also, a biowell is not recommended, since a comparison of Cases 5 and 6 shows no advantage.

In the event that the assumptions concerning the attenuation of the artificial electron flux are later found to be in error, Cases 13 through 24 were completed to determine the severity of this occurrence. These analyses were

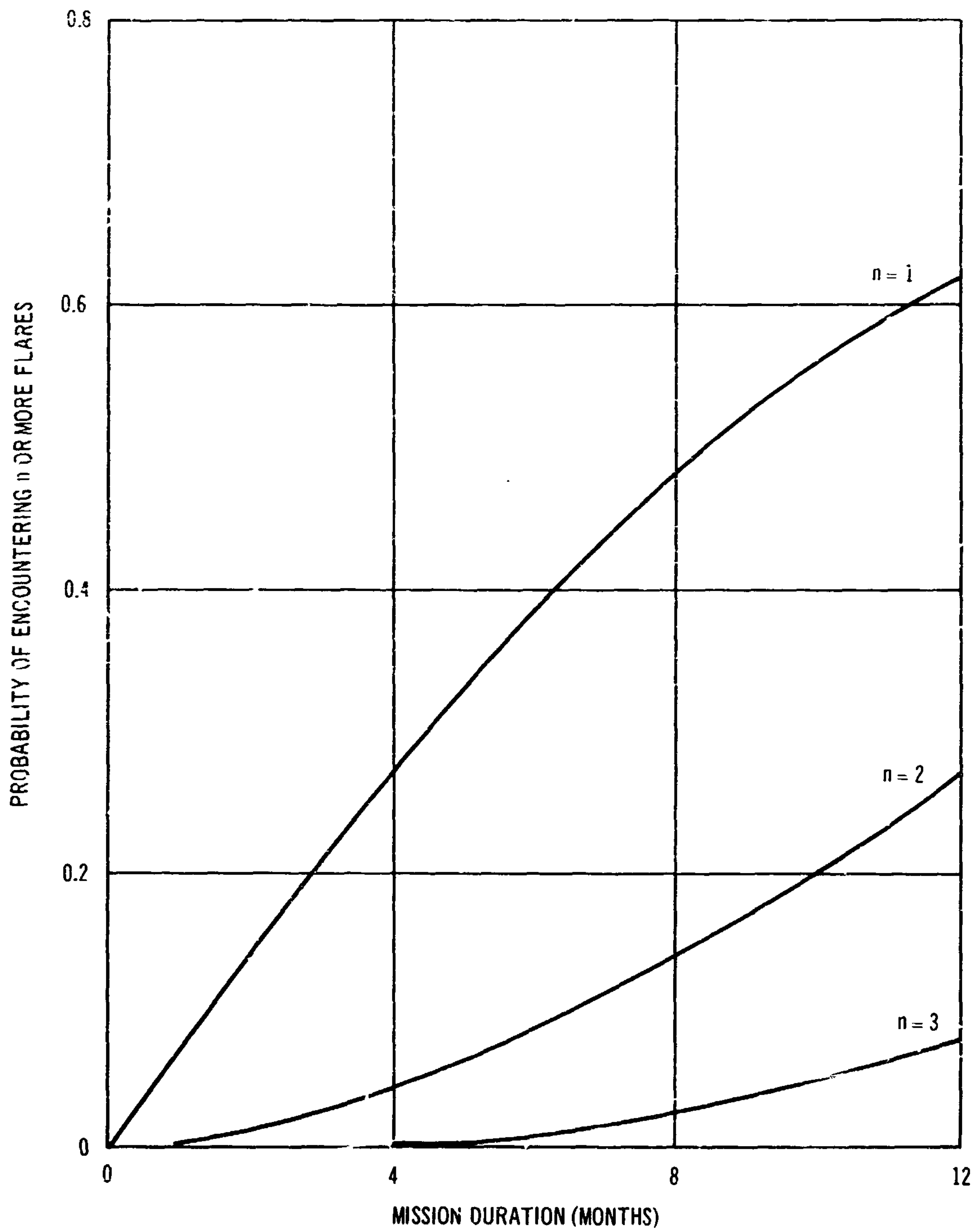


Figure 6-5. Probability of Encountering n or More Flares as a Function of Mission Duration

conducted with the levels of electron flux that would be present in 1968 and beyond as based on an extrapolation of the current decay rate as discussed in Section 6.1. The effect of this phenomenon would be to increase the shield weight requirements to 1,650 lb, as seen in Case 17 in order to provide the same protection described in the preceding sections. This shield could be provided by adding 0.07 in. of polyethylene to the baseline laboratory cylindrical sides and 0.51 in. to the dome, or their equivalent weight in aluminum.

The effect of a biowell is shown by comparing Cases 17 and 18. A reduction of 160 lb (9%) could be achieved by incorporating a biowell. However, this small savings would not offset the additions and restrictions necessary to implement a biowell, which would therefore, not be recommended. The effect of the solar cycle variation is significant as seen by comparing the data of Cases 17 and 24. This is because the dominant radiation source is the trapped protons as seen in Figure B-5 and B-6. The trapped proton flux level at low altitudes is inversely related to the atmospheric density (Reference 1) and is lowest at the solar maximum. The flux variation from solar maximum to solar minimum is by about a factor of 2.5, thus causing the change in shield weight requirements (about 20%) between Cases 17 and 24.

6.3.3.2 The Polar, 200-nmi Altitude, 90° Inclination Mission

The basic dose attenuation curves for the 200-nmi altitude, 90° inclination mission are shown in Figures B-3, B-7, and B-8. From Figure B-3, it can be seen that for the shield thicknesses of interest (10 gm/cm^2), the solar flare proton environment is higher by about a factor of three, than that encountered on the 50° mission. Figures B-7 and B-8, show that the dominant trapped radiation source is trapped protons.

The shield requirements and dose data for the polar mission are listed in Cases 25 through 36 of Table 6-4. Cases 25 through 30 correspond to the assumed design condition that the artificial electron source will be attenuated to a negligible value. The controlling dose criteria is the single dose limit of 100 REM to the skin and lens of the eye (Table 6-1). The single dose received from a solar flare determines the shield weight requirements. Thus, the results are independent of mission duration. Since this dose limit is for each solar flare, the shield requirements for one or two solar flares are identical (within the calculational iteration step values). Thus, a shield weight of 1,820 lb will also provide adequate protection for two solar flare events. The integrated dose to the skin and the lens of the eye would exceed the limit if three solar flares were encountered. With a shield weight of 1,820 lb (protection for two flares). the probability of exceeding the dose limit is only 0.01 for a 6 month period and 0.08 for a 1-year mission (Figure 6-5). Since the intermittent solar flare radiation is the controlling factor, the use of a biowell may be worthwhile. This biowell is a heavily shielded portion of the laboratory in which the crew would reside for the flare duration. Comparing Cases 27 and 28, the saving in shield weight by incorporating a biowell is seen to be 1,460 lb. This large weight saving could very well offset the restrictions imposed by the biowell. However, until this tradeoff study is completed, the recommended shield weight for the polar mission would be 1,820 lb. This shield could be provided by adding 0.21, 0.39, and 0.06 in. of polyethylene, or their weight equivalent of aluminum, to the bottom, sides, and dome top of the laboratory, respectively. This large weight penalty could be easily accommodated because of the large discretionary payload available on this mission, which would use a Saturn V launch vehicle. If the weight penalty did become restrictive for some reason, then the biowell tradeoff should be evaluated.

These analyses were repeated for the case where the artificial electron flux was attenuated by a factor of 5.9 from the mid-1963 level as discussed in Section 6.1. These results are presented in Cases 31 through 36 for the polar mission. The single dose criteria and the integrated dose criteria are about equally predominant as controlling factors as can be seen by comparing the dose received to the allowable dose (Table 6-1). The resultant shield weight requirements would not be greatly increased from the design conditions discussed above, however. The weight required for protection on a 180-day mission would be 2,410 lb, assuming protection for 2 major solar flare events. This shield would be applied to the laboratory bottom, sides, and top dome at depths of 0.15, 0.32, and 0.39 in. of polyethylene respectively, as shown in Case 33. The use of a biowell, although it would save about 1,000 lb, would not be recommended at this time because of the large payload capability of the launch vehicle and the fact that the requirements and penalties associated with the biowell have not yet been determined. A comparison of Cases 31 through 36 further indicates that the effect of the solar cycle would be minimal on the shield weight requirements.

6.3.3.3 Synchronous Mission

The basic dose attenuation data for the synchronous mission (19, 350-nmi altitude and 28.3° inclination) are shown in Figures B-3 and B-4. The effect of the solar flare protons is seen to be the highest of the three missions considered in Figure B-3. The only significant background radiation source at this orbit altitude is the electron-bremsstrahlung source shown in Figure B-4. At this altitude, there is no variation with solar cycle activity. However, there are other variations, the effects of which will be examined.

The shield weight requirements for this mission are shown in Cases 37 through 42 of Table 6-4. These data are for the nominal value of electron flux. From these results, it can be seen that the shield requirements indicated are quite high (> 20 tons). Further, the mission duration or the use of a biowell does not significantly affect the weight requirements over the ranges considered. The required shield thicknesses are up to 10 in. of polyethylene. The biowell does not appreciably reduce the required shield weight, because most of the dose comes from the background electron-bremsstrahlung source.

In Section 6.1, the uncertainty in the value of the electron flux at this orbit condition was discussed and found to be about plus or minus an order of magnitude. The shield analysis was conducted with this variation, and the results are shown in Figure 6-6. The uncertainty factor of 1.0 represents the analysis reported in Cases 37 through 42 of Table 6-4 for the present estimate of the nominal radiation environment. The uncertainty in the electron flux of an order of magnitude causes a variation in the shield weight requirement of from 4, 400 to 110, 000 lb, as shown in Figure 6-6. The above shield requirements are quite a bit higher than those reported in previous analyses; Section 6.1 outlines the reasons for these high values.

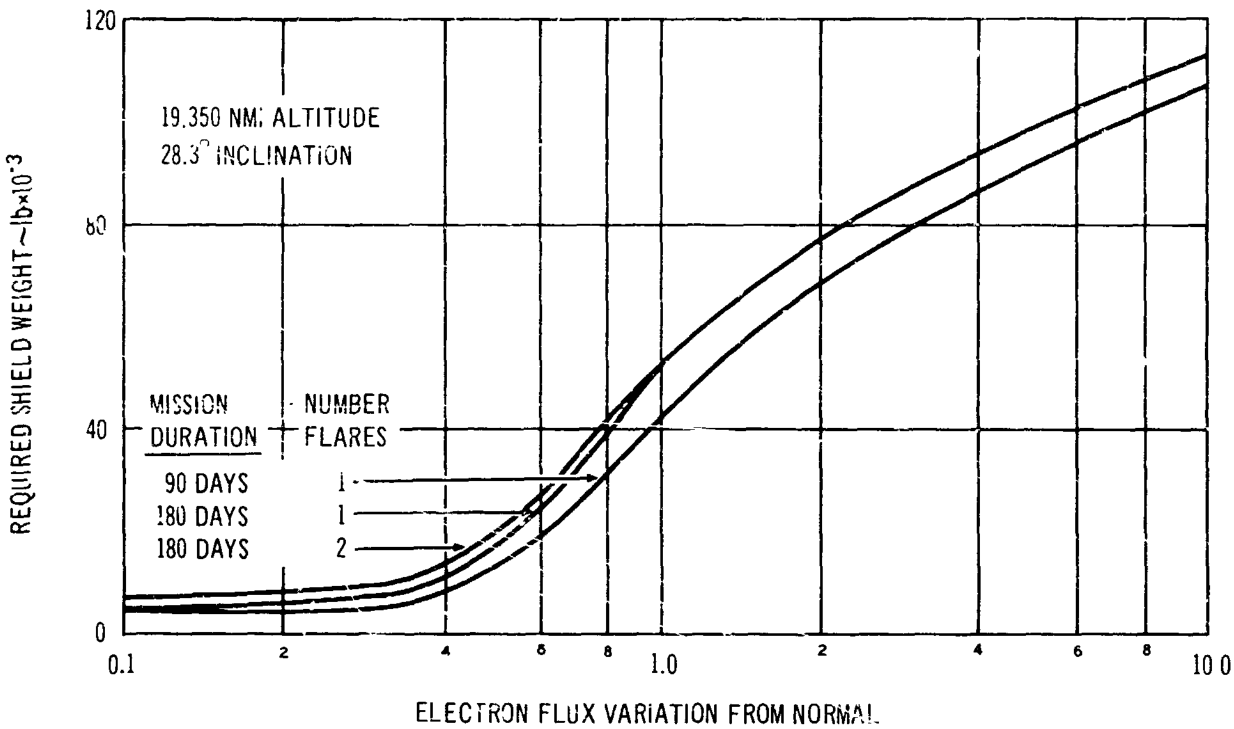


Figure 6-6. Variation in Radiation Shield Weight Required Because of Flux Uncertainty

The shield requirements presented in this report appear excessive for two reasons. First, the weight required may surpass the maximum that could be allotted for radiation protection on the laboratory launch (about 30,000 lb.- assuming no discretionary payload). Second, even if it could be resupplied, the weights may be quite formidable, and the task of installing the material to a thickness of 10 in. or greater seems out of the question. Other problem areas in this regard are discussed in Section 4.2.6 of this report.

The conclusion at this state of the study is that the radiation shield weight required for the synchronous mission appears excessive and that serious studies must be undertaken prior to committing the MORL concept to this mission. The following areas should be examined to resolve this problem:

1. The synchronous mission must be defined such that the minimum acceptable laboratory volume can be determined. It must be borne in mind that the present MORL was designed to operate in a moderate radiation environment; thus, this environment was not a strong influencing factor on the design. With the radiation environment explicitly included, future configuration studies may well result in a reduction in the amount of area that must be shielded and thus reduce the weight proportionately.
2. The effectiveness of using on-board materials such as water and propellant should be determined. This solution would be particularly effective if the livable volume could be significantly reduced.
3. Personal portable shields should be evaluated to determine the weight saving that could be achieved and also the restrictions they would impose.
4. The use of laminated shield materials should be evaluated in order to take advantage of the properties of various materials.
5. The physical task of attaching thick shield material to the laboratory on the ground or in orbit must be examined to determine the restrictions and interactions with other subsystems and experiments.
6. The allowable dose criterion should be reviewed to see if it could be relaxed for the synchronous mission.
7. The electron flux at synchronous altitude must be defined.

Section 7
TASK IV RECOMMENDATIONS

On the basis of the analyses of the Task III effort, the following recommendations are made for further study in Task IV and future work:

1. Mission Analysis
   - A. The possibility of attaining a polar orbit by launching down 146° azimuth, then doglegging over Cuba and Panama be ascertained.
   - B. A detailed study to determine the minimum launch windows that can be confidently met with the S-IB and Saturn V vehicles be made.
   - C. An evaluation of the merits and problems associated with incorporating a 9-man crew into the MORL be undertaken.
   - D. The practical limits of cross-training of the crew members be determined so as to increase the skill-mix capability.
2. Environmental Control/Life Support System
   - A. The EC/LS radiator be resized for the synchronous mission.
   - B. A separate cooling and ventilation system be installed in the hangar section to provide better temperature control and comfort for the crew. This is because of the increased occupancy of this area in carrying out the Experiment Plan.
3. Stabilization and Control System
   - A. Those experiments requiring high slew rates or tight rate stabilization control be provided with a gimballed mount.
   - B. Further verification of the ability of the SCS to maintain the attitude within 0.5° be accomplished.
   - C. The motions induced into the laboratory by crew movement be evaluated to a finer degree.
   - D. Further studies to verify the capabilities of the precision attitude reference be accomplished.
   - E. A rigid external experiment sensor mount be installed.

PRECEDING PAGE BLANK NOT FILMED.

4. Communications and Telemetry

    A. An S-band system to maintain reasonable data rate transmission be installed for the synchronous mission.

    B. The communications facility in Guaymas be added to allow for adequate data transmission for the polar mission.

    C. The baseline Data Management System be re-evaluated in the light of recent advances in present technology and also the much larger capacity that will be required when a large experiment program is undertaken.

5. Configuration and Structures

    A. Methods of attaching various amounts of radiation shielding to be detailed. This should include both installation on the ground and in orbit.

    B. A new console and operator panel be installed in the hangar section to accommodate the experiment activity in that area.

    C. The laboratory scientific console be enlarged to accommodate multiple experiment control capability.

    D. The feasibility of constructing an external experiment mount which could maintain very tight dimensional stability be determined.

    E. Rearrangements of the laboratory interior be evaluated in an attempt to increase the radiation shield capability of the basic structure.

    F. The overall requirements of the biowell area be determined.

6. Radiation Analysis

    A. A study to determine better radiation environment and variations therein be done. This should be accomplished for both the high and low altitude regions (200 nmi and synchronous). The degree to which the artificial electron belts are present should especially be determined.

    B. The mechanism by which bremsstrahlung is formed be verified to increase the confidence in the shield weight requirements.

    C. Alternate shield methods be evaluated to decrease the large weight presently required for the Synchronous Mission. This should include other materials such as water, and new shield concepts such as small modules, laminated shields, and personal shields.

    D. Methods of attaching thick shield materials to MORL be investigated.

E. The SWORD digital program be improved to include more dose points and more flexible dose criteria capability.

F. The allowable dose criteria be reviewed to see if it could be relaxed for the Synchronous Mission.

7. Experiment Definition

The experiment requirements be re-evaluated (especially those imposed upon the SCS and Communication Systems) to determine whether they can be relaxed in some areas without compromising the success of the experiment. To accomplish this, the respective subsystem talents must be applied at the experiment definition level.

REFERENCES

1. Geomagnetically Trapped Radiation. Douglas Report No. SM-47635, October 1964.
2. Report on the Development of the Manned Orbital Research Laboratory (MORL) System Utilization Potential. Task Area II Integrated Mission Development Plan, Book 1. Douglas Report No. SM-48810, October 1965.
3. Development of the Manned Orbital Research Laboratory (MORL) System Utilization Potential, Interim Report. Douglas Report No. SM-48157, February 1965.
4. Report on the Optimization of the Manned Orbital Research Laboratory (MORL) System Concept, Vol. VI, System Analysis – Mission Profile Data. Douglas Report No. SM-46077, September 1964 (S).
5. Report on the Optimization of a Manned Orbital Research Laboratory (MORL) System Concept, Vol. XII, Laboratory Mechanical Systems – Structures. Douglas Report No. SM-46083, September 1964
6. Apollo X Final Report: Extended Apollo Systems Utilization Study, Vol. 2 through 18. North American Aviation Report No. SID 64-1860, November 1964 (C).
7. Modified Apollo Logistics Spacecraft Study, Final Report Vol. I, Summary. North American Aviation Report SID 63-1461, December 1963 (C).
8. Apollo X Final Report: Extended Apollo Systems Utilization Study, Vol. I, Summary. Report on the Optimization of a Manned Orbital Research Laboratory North American Aviation Report SID 64-1860, November 1964 (C).
9. (MORL) System Concept, Vol. XX, Logistics Systems. Douglas Report No. SM-46091, September 1964 (C).
10. Extended Mission Apollo Study, Final Report Vol. IX, Space Environment, Structures and Weights. North American Aviation Report SID 63-1370, November 1963 (C).
11. Radiation Guidelines for Manned Space Vehicles – A Review with Recommendations, Douglas Report No. SM-47749, July 1965
12. Computer Analysis of Radiation Shielding. Northrop Space Laboratories No. AMD-TRD-62, August 1963.

PRECEDING PAGE BLANK NOT FILMED.

13. Report on the Optimization of a Manned Orbital Research Laboratory (MORL) Systems Concept, Vol. VIII, Effectiveness Studies — Alternate Missions. Douglas Report No. SM-46079, September 1964.

14. Report on the Development of the Manned Orbital Research Laboratory (MORL) System Utilization Potential. Task Area II, Integrated Mission Development Plan, Book 2 and Book 3. Douglas Report Nos. SM 48811 and SM 48812, October 1965.

15. Report on the Development of the Manned Orbital Research Laboratory (MORL) System Utilization Potential. Task Area I, Analysis of Space Related Objectives, Book 2. Douglas Report No. SM-48808, September 1965.

16. Charge, A Space Radiation Shielding Code. Douglas Report No. SM-46335, April 1965.

17. Final Review--Modified Apollo Logistics Spacecraft, North American Aviation Report SID 63-1459, December 1963 (C).

Appendix A
THE SYSTEMS EFFECTIVENESS AND EVALUATION PLANNING DEVICE (SPEED)

A. 1 PROGRAM DESCRIPTION

The method used to obtain the timelined Experiment Plan, included in the jacket attached on the back cover of this report, and an assessment of its impact on the laboratory centers around a computer program specifically developed for this purpose. This computer program represents an evolutionary step from previous programs that have similar objectives. Unlike its predecessors, the System Planning and Effectiveness Evaluation Device (SPEED) attempts to simulate (in a Monte Carlo mode) and schedule all activities that occur on board any ORL. Thus, experimentation, scheduled and unscheduled maintenance, system and subsystem failures, crew performance, and general housekeeping activities are among the events modeled.

The fundamental mode of operation of the SPEED program is indicated in Figure A-1. The main product of the orbital facility is recognized to be the experimental activity performed by the crew, and the simulation attempts to represent the events and conditions that may affect this activity.

Thus, it is recognized that the performance of experiments requires two basic primary resources: equipment and human skills. However, these primary resources are supported or owned by certain so-called secondary resources. For instance, equipment occupies space and draws power. Therefore, pressurizable volume and electrical power constitute secondary resources. In this context, specific individuals in the crew are also considered secondary resources, since, for example, Man A can be thought of as providing the particular skill called mathematician.

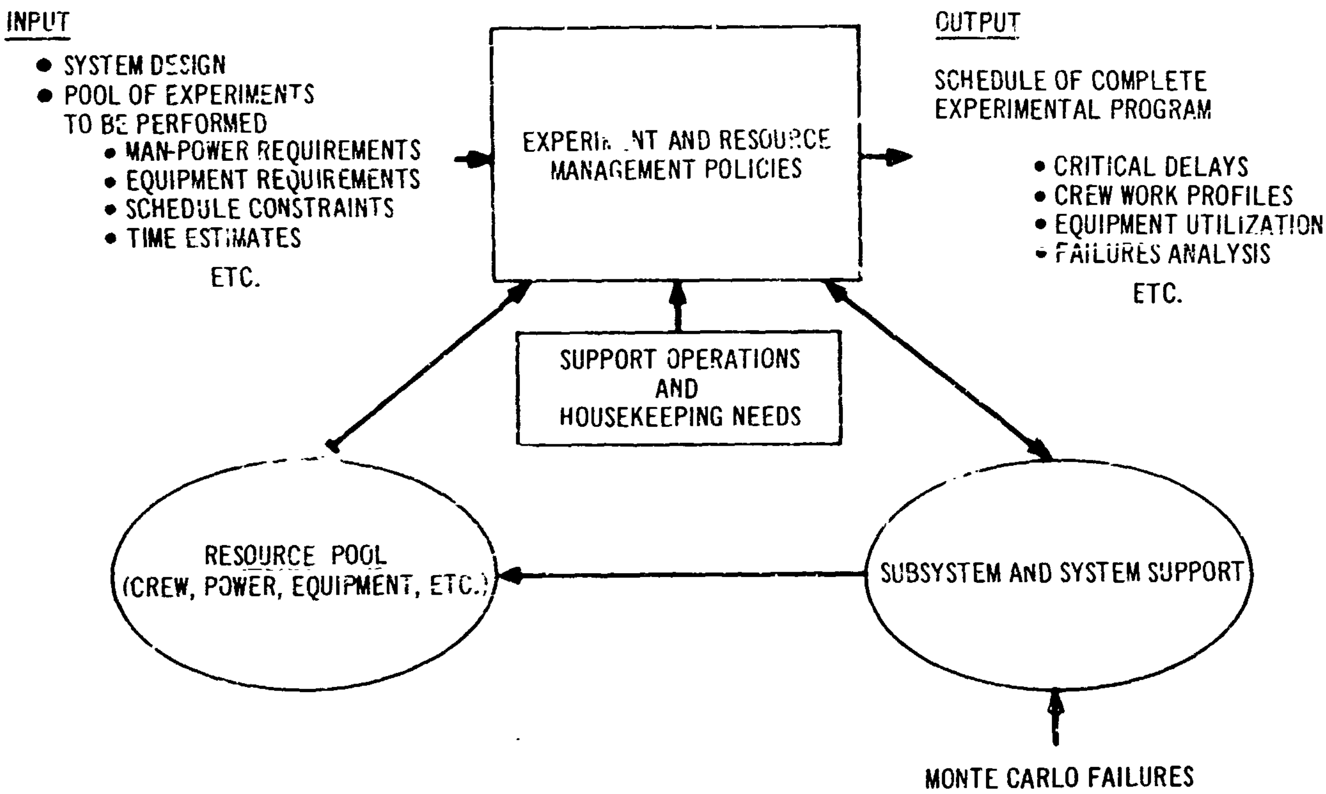


Figure A-1. Speed Simulation Model

However, secondary resources are supplied by laboratory subsystems. For instance, pressurizable volume is supplied by the structures subsystem, power is supplied by the electrical power system, and specific individuals in the crew can be thought of as belonging to the subsystem called the crew.

In turn, subsystems depend on certain crew activities, such as maintenance, repair, resupply operations, and other housekeeping and station-operation functions. Even the crew subsystem must be maintained by suitable physical conditioning, rest, and recreation allowances. Finally, the model recognizes that such support activities also draw on primary resources; for instance, certain equipment and skills are required to perform repairs, maintenance, and other functions.

The simulation represents, therefore, a closed cycle, each element of which depends on other elements. This dependency is best illustrated by a discussion of how subsystem failures are handled in the simulation.

If, for instance, the power system fails, power (the secondary resource) is reduced by an amount appropriate to the nature of the failure. In some cases, this may constitute a loss large enough to preclude the operation of certain primary resources that draw on power. If that is the case, the simulation will remove from the line those experiments that utilize the concerned equipment.

However, as a failure may reduce some resources, it may increase the availability of others. In the above example, additional crewmen may become available as a result of interrupting experiments and may then be shifted to a repair operation.

The simulation includes other potential complications. If the power failure is serious enough, provision is made to model loss of performance in other subsystems. For instance, the power available to the life-support system may be reduced, causing a reduction of its output to the crew, which, finally, is presented by the simulation as reduced work capability.

However, as was indicated in the above description of the closed-loop nature of the laboratory, repair operations also draw on resources. If adequate resources are unavailable, a repair cannot be effected. Thus, if the reduced crew performance resulting from the postulated power failure is too great, the power failure cannot be repaired and the laboratory mission is a failure.

Thus, the simulation model heavily emphasizes the interdependence of major laboratory subsystems and resources in general, the interdependence of the crew and the laboratory in particular. Experiments are scheduled in the presence of this realistic model, subject to the resources available for experimentation after resolution of all conflicting demands. Additional constraints on scheduling experiments are (1) the completion of logical predecessors as determined from the Applications Plan analyses and (2) a preference code that, other conditions being equal, will force the initiation of certain experiments before others.

A. 2 THE SPEED INPUT SYSTEM

The inputs to the SPEED program can be grouped into three major blocks. The first block of data controls certain program operations, such as the reports to be generated and the number of replications desired. The second data block describes the experiments to be simulated and scheduled in terms of the requirements they impose on the laboratory, such as crewskills, crewtime, power, weight, volume, and equipment to be provided. Thus, the second block of data consists of information on the experiment briefs documented in References 14 and 15 .

The third block of data describes the ability of the MORL to meet these requirements in terms of the availability of the resources demanded by the experiments. Thus, the availability of each crewman during the day is described; the power, weight, volume, and availability of equipment is stated; and the association of specific skills with specific individuals in the crew is defined. The interconnection of these resources with major laboratory subsystems is also defined. For instance, the operation and availability of certain equipment may be made dependent on the operation of the power subsystem and the data processing and telemetry subsystems. Thus, if either or both of these subsystems fail, so as to reduce performance capability by a stated amount, the equipment in question becomes unavailable.

The reliability of subsystems is also defined in the third data block. In this case, definition is accomplished by assuming an exponential failure distribution and giving the MTBF of the subsystem. The repairs to be initiated in case of failure are also input for each subsystem. The skills, equipment, and other resources demanded by repairs and the permissible delays in initiating and completing repairs are part of this input.

Finally, certain basic laboratory operations (support operations), are described and input. Support operations are those operations that the crew must perform at stated times during the day. These operations have absolute priority on all resources and, thus, have priority even over repair operations.

It is a philosophical point to decide what operations should be placed into this category. It is perhaps unnecessary to regard any activity as being of such overwhelming importance as to be classified a support operation. However, to follow an extremely conservative philosophy regarding the safety and well-being of the crew designated rest periods, basic exercise periods, and housekeeping activities were input as support operations.

A. 3 EXPERIMENT PLAN INPUTS

This section describes specific data input to SPEED to develop the Experiment Plan.

Figure A-2 gives the availability of each crewman for experimental work. The skills possessed by each crewman are also indicated through skill code numbers. Skill code numbers and other resource code numbers are defined in Table A-1. Figure A-3 defines the availability of shipping weights, shipping volume, and electrical power as a function of time. Finally, Table A-2 defines the effects and probability of occurrence of subsystem failures as well as their repair requirements.

A. 4 FISHERIES PRODUCTION PROGRAM INPUTS

This section describes specific data inputs to SPEED runs testing the responsiveness of MORL to an objective-oriented (Fisheries Production Assistance) experimental program. These runs were conducted with a nine-man crew. Figure A-4 defines the availability of the crew for experimental work and skill mixes assumed for the three runs made. Skill and other resource code numbers are explained in Table A-3.

The three runs made differ only with respect to crew skill mixes assumed. The changes in crew skill mixes from run to run are defined in Table A-4.

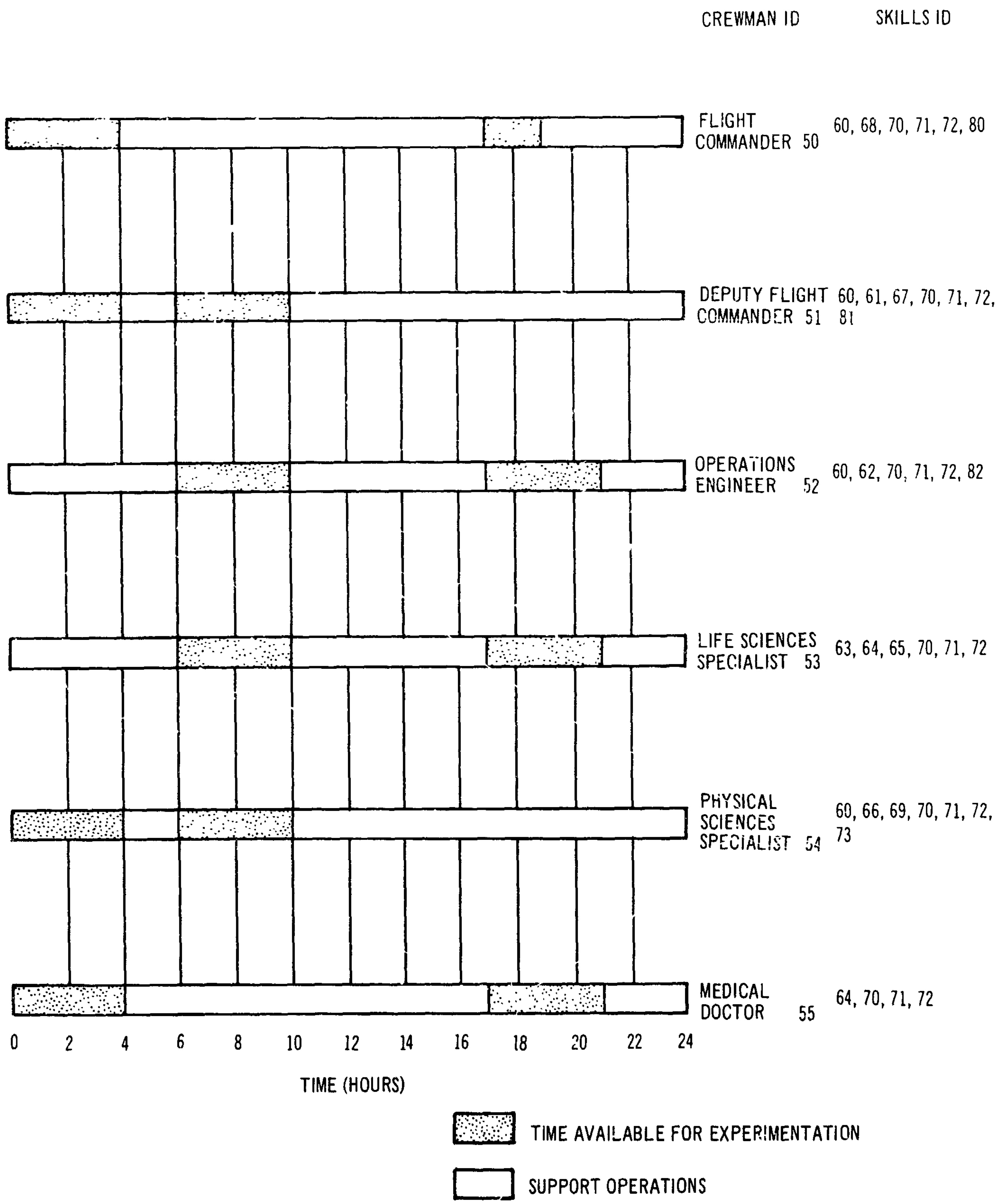


Figure A-2. Crew Availability Cycle (6-Man Laboratory Total Experiment Time = 45.8 Hours)

Table A-1

RESOURCE CODES AND DEFINITIONS (page 1 of 2)

Code Number	Name	Type	Maximum Value
Resource 1	Electrical power (watts)	Subsystem output	2,550
Resource 2	Shipping weight (lb)	Logistics	226,000
Resource 3	Shipping volume (cu ft)	Logistics	22,600
Resource 10	TV system	Equipment	5
Resource 11	IR radiometer	Equipment	5
Resource 12	Microwave radiometer	Equipment	5
Resource 13	Radar	Equipment	5
Resource 14	Lidar	Equipment	5
Resource 15	IR interferometer	Equipment	5
Resource 18	S-band polarimeter	Equipment	5
Resource 19	Camera	Equipment	1
Resource 50	Flight commander	Crewman	1
Resource 51	Deputy flight commander	Crewman	1
Resource 52	Operations engineer	Crewman	1
Resource 53	Life sciences specialist	Crewman	1
Resource 54	Physical sciences specialist	Crewman	1
Resource 55	Medical doctor	Crewman	1
Resource 60	Electrical/mechanical technician	Crew skill	1
Resource 61	Optical technician	Crew skill	1
Resource 62	Electrical engineering specialist	Crew skill	1
Resource 63	Physiologist	Crew skill	1
Resource 64	Medical technician	Crew skill	2
Resource 65	Biotechnology specialist	Crew skill	1
Resource 66	Meteorological specialist	Crew skill	1
Resource 67	Oceanographic specialist	Crew skill	1
Resource 68	Astronomy/astrophysics specialist	Crew skill	1

Table A-1 (page 2 of 2)

Code Number	Name	Type	Maximum Value
Resource 69	Physicist	Crew skill	1
Resource 70	Subject	Crew skill	6
Resource 71	Observer	Crew skill	6
Resource 72	General worker	Crew skill	6
Resource 73	Photo-technician/cartographer	Crew skill	1
Resource 80	EC/LS repair specialist	Crew skill	1
Resource 81	RCS, SCS, structure repair specialist	Crew skill	1
Resource 82	Communications, telemetry, and power repair specialist	Crew skill	1

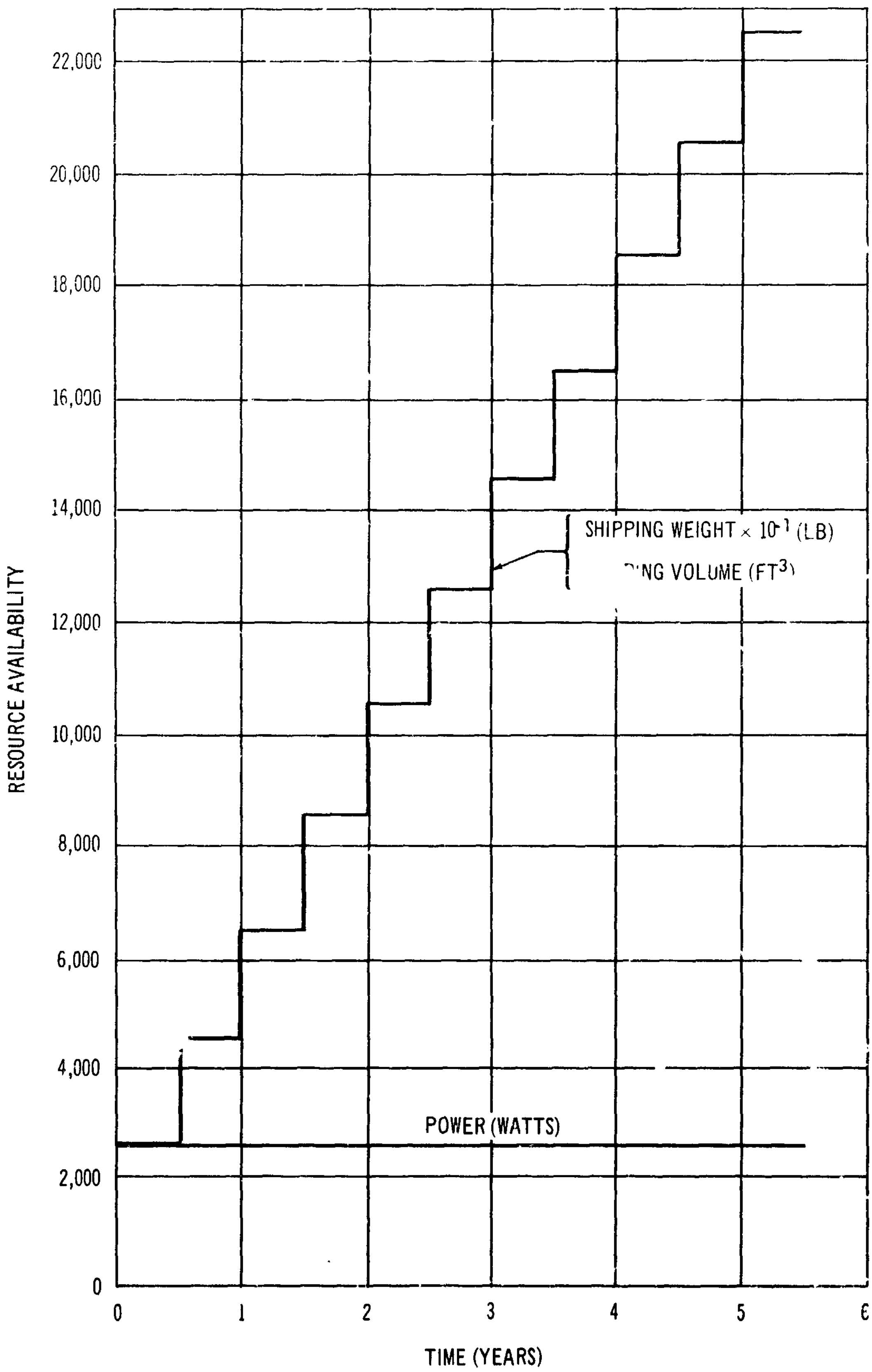


Figure A-3. Maximum Resource Availability

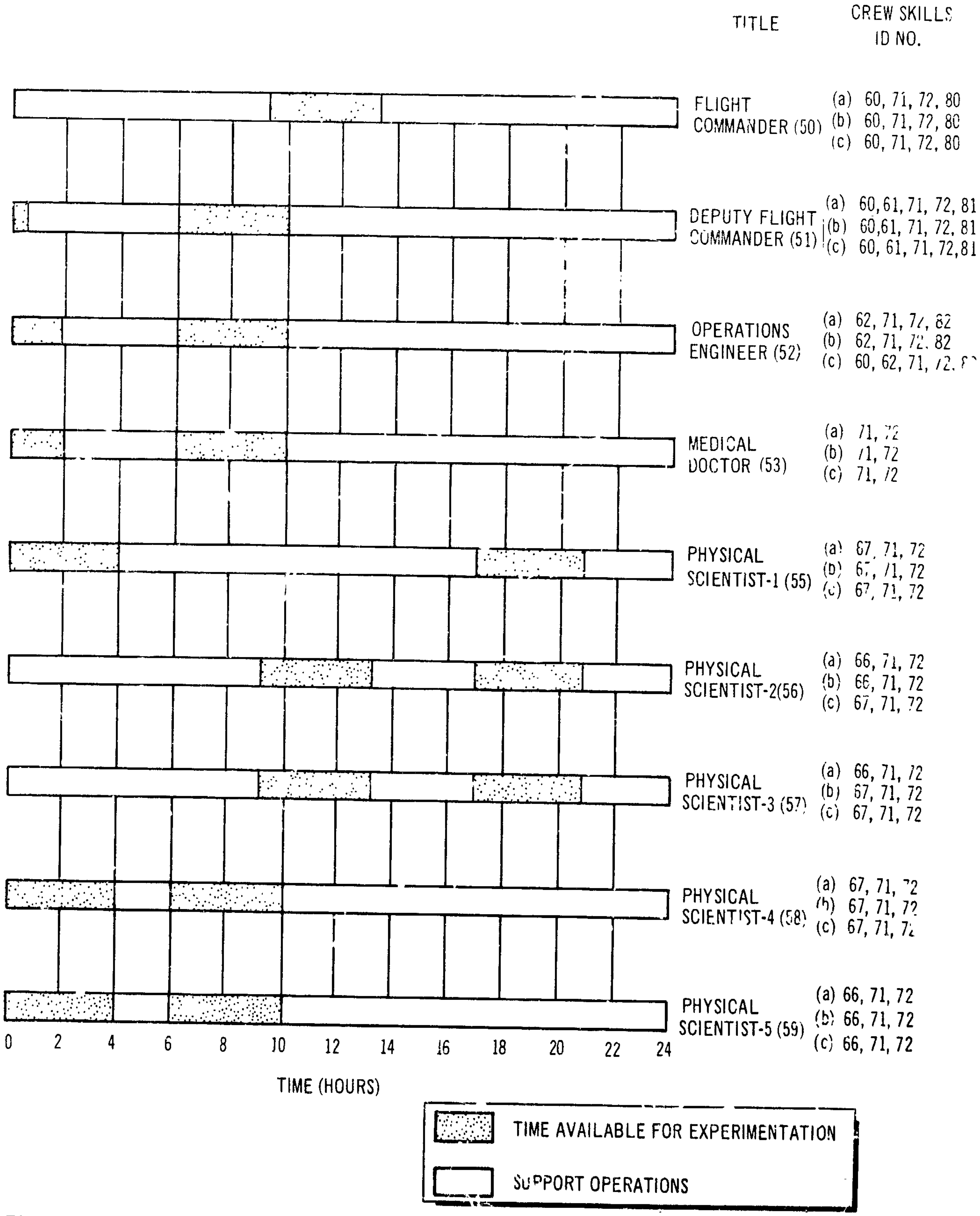


Figure A-4. Crew Availability Cycle (9-Man Laboratory Total Experiment Time = 60.3 Hours)

Table A-2

SUBSYSTEM FAILURE AND REPAIR DEFINITION

ID[1]	MTBF[2] (Hours)	Probability of Turn-On[3]	Probability of Spares[4]	Maximum Allowable Repair Time[5] (Hours)	Laboratory Response Time[6] (Hours)	Effect Upon Laboratory Resource[8] ID[1]	Amount[7]	% Restored	Repair Resource Profile
1 (Power)	1.09×10^6	0.999	0.98	72	0.005	1	2,000	1	1 [81] 0 2
2 (ECLS)	3,150	0.999	0.98	72	0.005				1 [80] 0 1
3 (SCS)	13,100	0.999	0.98	72	0.1				1 [81] 0 2
4 (Communications and Telemetry)	3,500	0.999	0.98	72	0.01	11 12 18 19	5 5 5 5	1 1 1 1	1 [82] 0 2
5 (RCS)	175×10^6	0.999	0.98	96	0.1				1 [81] 0 4; 1 [81] 24 28
6 (STRUCT)	0.62×10^6	0.999	0.98	96	0.1				1 [81] 0 4; 1 [81] 24 28

[1] ID--The identification code for each subsystem and resource.

[2] MTBF (hours)--The Meantime Between Failures, in hours, for this subsystem.

[3] Probability of Turn-On--The probability of the subsystem turning on at the beginning of operation and after a repair operation has been completed.

[4] Probability of Spares--The probability that sufficient spare parts are onboard the laboratory to effect the repair.

[5] Maximum Allowable Repair Time--The maximum time (hours) allotted for completion of repairs on this subsystem before a laboratory catastrophy occurs.

[6] Laboratory Response Time--The response time of the laboratory to a failure in this subsystem.

[7] Amount--The amount of this resource lost as a result of the failure.

[8] Effect upon Laboratory Resources--Definition of the impact of the subsystem failure on laboratory resources.

[9] % Restored--The percentage (1.0 = 100%) of this resource requirement profile necessary to affect repair of the subsystem.

[10] Repair Resources Profile--Definition of the resource requirement profile necessary to affect repair of the subsystem.

Example:

1 [81] 0 1 Time (Hour) — Requirement profile time scale, defining the resource skill ID (81) and amount necessary (1).

Table A-3

RESOURCE CODES AND DEFINITIONS (page 1 of 2)

Code Number	Name	Type	Maximum Value
Resource 1	Electrical power (watts)	Subsystem Output	2, 550
Resource 2	Shipping weight (lb)	Logistics	226, 000
Resource 3	Shipping volume (cu ft)	Logistics	22, 000
Resource 11	IR radiometer	Equipment	5
Resource 12	Microwave radiometer	Equipment	5
Resource 18	S-band polarimeter	Equipment	5
Resource 19	Camera	Equipment	5
Resource 50	Flight commander	Crewman	1
Resource 51	Deputy flight commander	Crewman	1
Resource 52	Operations engineer	Crewman	1
Resource 53	Medical doctor	Crewman	1
Resource 55	Physical scientist (1)	Crewman	1
Resource 56	Physical scientist (2)	Crewman	1
Resource 57	Physical scientist (3)	Crewman	1
Resource 58	Physical scientist (4)	Crewman	1
Resource 59	Physical scientist (5)	Crewman	1
Resource 60	Mechanical/photo technician	Crew skill	*(a) 2 (b) 2 (c) 3
Resource 61	Mechanical engineer and optics specialist	Crew skill	1
Resource 62	Electrical engineer and mechanic	Crew skill	1
Resource 66	Meteorological specilist	Crew skill	*(a) 3 (b) 2 (c) 1

Table A-3 (page 2 of 2)

Code Number	Name	Type	Maximum Value
Resource 67	Oceanographic specialist	Crew skill	*(a) 2 (b) 3 (c) 4
Resource 71	Observer	Crew skill	9
Resource 72	General worker	Crew skill	9
Resource 80	EC/LS repair specialist	Crew skill	1
Resource 81	RCS, SCS, structure repair specialist	Crew skill	1
Resource 82	Communication, telemetry, and power repair specialist	Crew skill	1

*(a) Two oceanographers, three meteorologists
(b) Three oceanographers, two meteorologists
(c) Four oceanographers, one meteorologist; additional skill of mechanic and photographic technician assigned to operations engineer.

Table A-4

NINE-MAN LABORATORY CREW SKILL DISTRIBUTION AMONG THE CREWMEN FOR EACH OF THREE RUNS

Orbit Altitude and Inclination	Case No.	Mission Duration (days)	Artif Electrons	Solar Cycle	No. of Solar Flares	Bio-Well	Total Shield Weight (lb)	Shield Thicknesses (in.) Main Shield T1	T2	T3	T4	T5	Biowell T6	T7	T8	Absorbed Dose (REM) Mission Total Eyes	Skin	BFO	Flare Total Eyes	Skin	BFO
	29	90	no	max	1	no	1,820	0.19	0.39	0.07						96	103		89*	97*	
	30	180	no	max	1	no	1,820	0.19	0.39	0.07						106	110		89*	97*	
	31	90	yes	min	1	no	2,200	0.18	0.34	0.27						148	170*	4	81	95	3
	32	180	yes	min	1	no	2,340	0.15	0.32	0.37						173	203	6	81	98	4
	33	180	yes	min	2	no	2,410	0.15	0.32	0.39						245	291	13	160	195	8
	34	180	yes	min	2	yes	1,420	0	0	0.3	0.61	1.02	0.53	0	0	244	290	13	108	122	6
	35	90	yes	max	1	no	2,200	0.18	0.34	0.27						142	163	3	81*	95*	2
	36	180	yes	max	1	no	2,340	0.15	0.32	0.37						161	190	4	81*	98*	2
19,350 nmi, 30°	37	90	-	-	1	no	42,000	2.6	3.9	8.0			-	-	-	86	—	50	7	—	2
	38	90	-	-	1	yes	41,800	1.4	3.1	9.2	4.0	5.1	0	0	0	86	—	50	4	—	1
	39	180	-	-	1	no	49,500	2.8	4.9	10.1			-	-	-	137	—	80	4	—	1
	40	180	-	-	1	yes	48,800	2.2	4.2	10.2	3.8	4.9	0	0	0	137	—	80	4	—	[illegible]
	41	180	-	-	2	no	50,[illegible]00	3.0	5.0	10.1			-	-	-	139	—	80	8	—	[illegible]
	42	180	-	-	2	yes	49,400	2.1	4.2	10.2	3.8	5.0	0	0	0	138	—	80	7	—	2

* Blood-forming organs

Appendix B
THE SHIELD WEIGHT OPTIMIZATION FOR RADIOBIOLOGICAL DOSE (SWORD) PROGRAM

B.1 GENERAL PROGRAM DESCRIPTION AND CAPABILITIES

Most space vehicle shielding programs are capable only of computing dose levels within a vehicle and shield of fixed geometry. In contrast, the SWORD program computes the optimal shield mass distribution which meets a set of radiobiological dose criteria associated with a specified vehicle configuration and mission profile. SWORD uses basic dose attenuation data produced by the OGRE (Orbital Geomagnetic Radiation Environment) and CHARGE computer programs for the specified vehicle trajectory, in conjunction with ray tracing computations performed on a generalized quadric surface representation of the vehicle, to compute dose levels to specified critical organs of crew members. The derivative of dose with respect to the thicknesses of candidate shield regions located at various surfaces of the vehicle is also computed. This information is then processed in an iterative procedure to determine the optimal shield mass distribution. The program both distributes shield material among such locations as wall structure, biowell, and personal shields, and shapes shielding over extended surface areas, with an optimization technique based on a particular formulation of the Lagrange multiplier constraint equations. SWORD can treat the effect of (1) multiple dose constraints (separate constraints for each organ), (2) time-dependent astronaut locations (the work-rest cycle influence), (3) organ-dependent RBE factors, and (4) direct and scattered neutron and gamma radiations from an on-board nuclear power source. The geometric framework, numerical integration schemes, and optimization procedures are sufficiently flexible and efficient to allow the analysis of a wide variety of space vehicle configurations.

The SWORD program was developed to satisfy the following two separate requirements related to radiation analyses for space vehicles: (1) to perform shield weight parametric studies during vehicle definition studies, and (2) to establish detailed shield mass distribution requirements for specific configurations.

For parametric studies performed during vehicle evolution studies, SWORD provides a consistent and rapid means of determining shield weight requirements for many meaningful system parameters. Typical parameters of interest include vehicle orbit, mission duration, launch date, vehicle geometry and internal arrangement, vehicle materials, radiation dose criteria, work-rest cycle influence on astronaut space-time position within the vehicle, and so forth. Because SWORD allows for treatment of a multitude of such parameters simultaneously, and because the shield weights computed are consistently optimized, the engineering evaluation of results is facilitated. In general the interplay of system parameters is sufficiently complex that the establishment of shielding requirements must be based on uniform, comprehensive analytical procedures. In addition, SWORD performs the necessary analyses efficiently both from computational and engineering standpoints. thus providing for rapid reevaluation of shield systems as configuration geometric details evolve and uncertainties in input data (such as the space radiation environment) are resolved.

SWORD is also capable of performing detailed studies of optimal shield mass distributions meeting specific radiation dose design criteria. For vehicles which are relatively well defined in geometry and materials, and for which the radiation environment and dose criteria are established, greater analytical detail is warranted than for parametric studies in which the primary goal is the total shield system weight. The CHARGE code, which provides basic dose attenuation data for specified material combinations, and the SWORD code include options on the detail with which numerical analyses are performed. In SWORD, these options include the number of dose points used to represent the location of radiation-sensitive body organs, the number of time-weighted astronaut stations, the number of discrete candidate shield locations, and the mesh size used in performing dose integrations over the 4π solid angle about each dose point location. Consequently, greater precision in numerical analyses can be attained, and the shield mass distribution requirements can be established more accurately.

The capability to investigate for a specific vehicle, the adaptation of a shield system from one set of design conditions to another, also exists. For example, it may be necessary to modify the shielding on a space vehicle to make it habitable for a differing set of space radiation environmental conditions. This may be a result of a specified change in the orbital parameters, or in the data defining the spatio-temporal distribution of planetary-trapped radiation. In such cases, SWORD is capable of accepting the existing shield mass distribution as a set of initial conditions, and then ascertaining the optimal placement of additional shield material required to meet the dose design criteria.

B.2 ANALYTICAL METHODS

The techniques used in SWORD include a numerical integration of the dose received at each dose point:

$$D\ (\vec{r}_{k,\ell}) = 1/4\pi \iint_{4\pi} K\ (\vec{r}_{k,\ell}, \vec{\Omega})\ d\Omega \qquad \text{(B-1)}$$

where

$\vec{r}_{k,\ell}$ = the position vector of the <u>kth</u> critical organ for the <u>ℓth</u> man-model location

$\vec{\Omega}$ = a unit direction vector

$K(\vec{r}_{k,\ell}, \vec{\Omega})$ = the dose that would be received at $\vec{r}_{k,\ell}$ if the materials encountered along $\vec{\Omega}$ were spherically symmetric about $\vec{r}_{k,\ell}$.

The integration involves ray tracings for a series of discrete rays defined by the azimuthal and polar angles. It includes primary and secondary space radiations, and direct and single scattered nuclear radiations. The space radiation dose data obtained through calculations by OGRE yield the time-integrated free-space radiation spectra, including mission parameter effects. Subsequent calculations by CHARGE yield dose attenuation for primary and secondary space radiation for basic shield materials in spherical geometry.

The total dose received by the kth critical organ involves a summation over the various man-model positions

$$D_k^T = \sum_{\ell} f_{\ell} D(\vec{r}_{k,\ell}) \tag{B-2}$$

where f_{ℓ} is the fraction of the mission spent in the ℓth location. The derivative of this dose with respect to the ith shield thickness, for example a unit vehicle shield thickness, goggle thickness for the eyes, and so forth, is calculated as

$$\frac{\partial D_k^T}{\partial t_i} = \sum_{\ell} f_{\ell} \frac{1}{4\pi} \iint_{4\pi} \frac{\partial K}{\partial t_i} (\vec{r}_{k,\ell}, \vec{\Omega})\, d\Omega \tag{B-3}$$

Each of the shield thicknesses is measured along the normal of the corresponding shielded surface.

The doses and their derivatives are used in a modified LaGrange technique which permits the simultaneous treatment of the dose-critical organs by forming the functions

$$U = W + \lambda V = \sum_i \rho_i t_i A_i + \lambda \sum_k \left(\frac{D_k^T}{C_k}\right)^n \tag{B-4}$$

where

- W = the total shield system weight
- A_i = the area of the ith shield location
- ρ_i = the shield material density
- λ = the LaGrange multiplier
- C_k = the dose constraint for the kth critical organ
- n = an exponent sufficiently large to emphasize the dominant constraint(s).

For nonoptimum shield designs, the derivatives of this function yield differing values of the LaGrange multiplier

$$\lambda_i = \rho_i A_i / n \sum_k \frac{1}{C_k} \left(\frac{D_k^T}{C_k}\right)^{n-1} \frac{\partial D_k^T}{\partial t_i} \tag{B-5}$$

The shield thicknesses are repetitively modified until the dose to each critical organ is less than the acceptable value. While building up the shield, the thickness for which λ_i is a maximum is incremented at each repetition. Iterations about the optimum point may involve removal of shielding, and the thickness for which λ_i is a minimum is then incremented. Each change in shield thickness requires the recalculation of the doses and their derivatives.

B.3 PROGRAM OPERATION

Some of the computational operations associated with shielding analyses performed by SWORD are outlined in Figure B-1. The figure also illustrates the interrelationships existing between the OGRE, CHARGE, and SWORD programs.

The operations performed in the six boxes pertaining to SWORD computations are as follows:

1. The input data defining dose point coordinates, and the angular structure to be applied in integrating dose contributions over solid angle, are used to define the origin and direction cosines of rays to be traced through vehicle materials other than shielding. The solid angle worth and Simpson's Rule weighting coefficients for each ray are computed. These operations are performed by a subroutine adopted from the previously developed SIGMA program.

2. The path lengths through each region penetrated by each ray are computed and then density-weighted to obtain the total mass (gram/cm^2) along the ray. If a neutron and gamma dose contribution, direct or single scattered, is computed for the ray, the total number of relaxation lengths for those radiations is also computed. For all shields penetrated by the ray, the indices of the shield region and the angle of penetration are determined; a maximum of three (nested) shields is allowed.

   Additional operations performed in Items 1 and 2 include the grouping of all rays penetrating each specified shielded surface area, for use in iterative shield optimization calculations. The surface area of each shield is also computed numerically to provide data on the relationship between shield thickness and weight.

3. The data tabulated for each ray are used to compute the dose contribution from space-radiation sources to be associated with the ray. This information is obtained by interpolation of tabulated basic dose attenuation data produced by the CHARGE code for the computed material thickness.

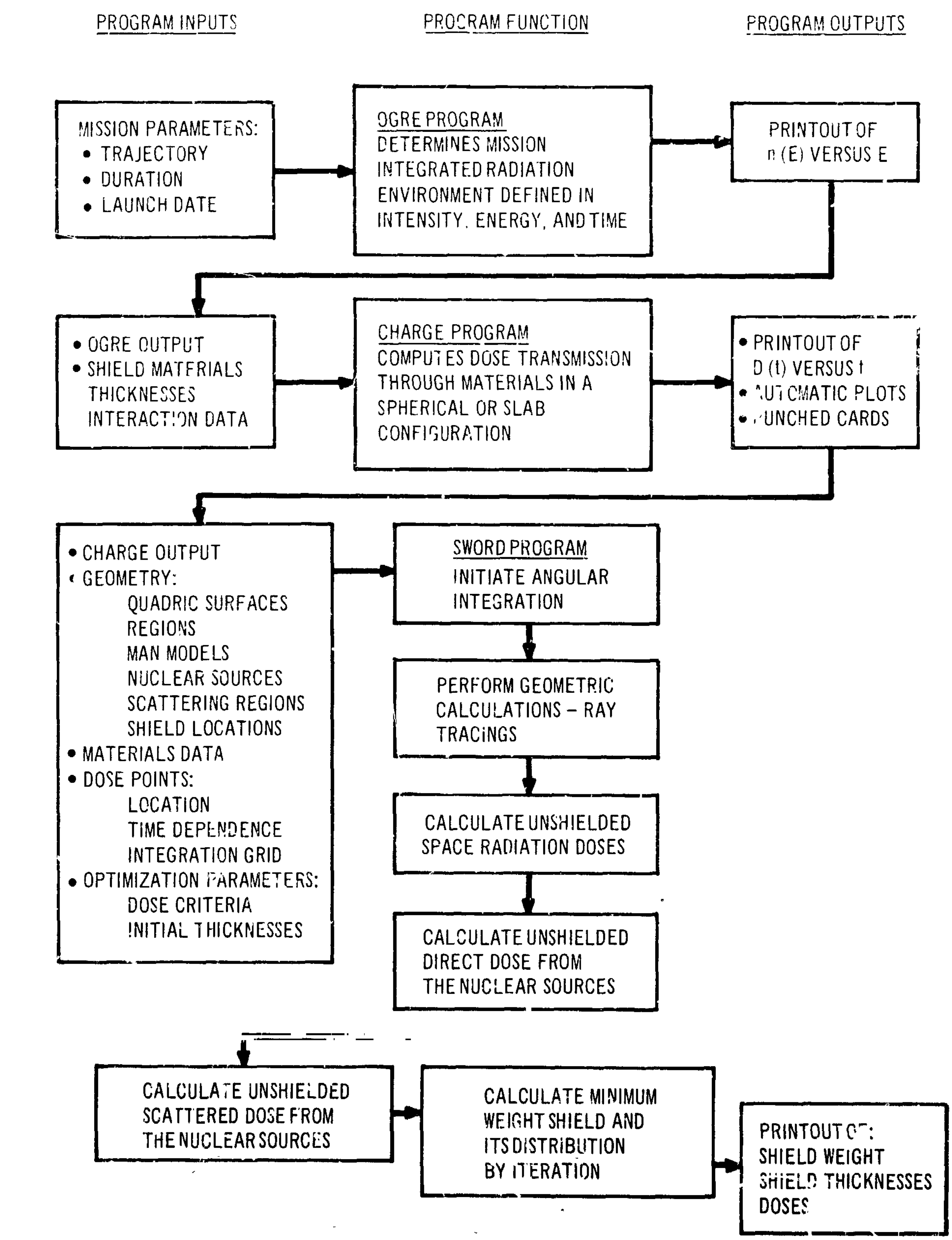


Figure B-1. SWORD Flow Diagram

4. The direct dose contributed by neutron and gamma radiation from each on-board nuclear source is computed by performing a point kernel integration over the active source volume. The attenuation of these radiations by vehicle materials is characterized by the material distribution along the path connecting dose point and source center.

5. The scattered radiation at each dose point from specified scattering regions pierced by rays traced during the angular sweep is computed. These data are established from direct fluxes at each scattering center, computed by the same procedure as the direct fluxes at the dose point, and from differential scattering cross-sections and models provided to the program. Attenuation of these radiations by vehicle materials uses the relaxation length data corresponding to the appropriate ray.

6. An iterative procedure, based on a multiple constraint formulation of the LaGrange multiplier technique, is used to establish optimal shield thickness. For this operation, the time-weighted doses to each critical organ at each astronaut station are summed for each set of shield thicknesses at each stage of the iteration. The derivatives of total doses with respect to each shield thickness are also repetitively evaluated. These data, together with data on the derivatives of total shield weight with respect to each variable, form the basis for incrementing or decrementing the shield thickness variables throughout the iteration. Only one shield thickness is modified at each step; for the particular shield involved, the list of rays penetrating the shield is consulted to construct revised dose and dose derivative values. These data are also revised for all other shields penetrated by such rays; no computations are performed for rays that do not penetrate the shield region which has been altered. When all dose criteria have been satisfied, and a weight convergence test is met, the calculation is terminated. During the iteration, any of the dose criteria may cease to influence the optimization operations, because of the dominance of other criteria, this circumstance is recognized automatically by the procedure.

B.4 COMPARISON OF OPTIMIZED AND NONOPTIMIZED, UNIFORMLY DISTRIBUTED SHIELDING

Some supplementary data were obtained which illustrate the importance of optimizing the shielding analyses. The data shown pertain to a MORL vehicle orbiting at 200 nmi, 90° inclination, for 180 days, during which 2 solar flare events are encountered. The data presented here illustrate (1) the weight savings obtained through shaping of shielding located at crew compartment wall structure, and (2) the convergence of dose values, to the levels specified as design criteria, during the iterative calculations of the optimization process.

Shield-shaping benefits were evaluated for the configuration which does not employ a biowell for solar flare protection. As discussed previously, the shield material was then distributed in an optimum manner among three areas located at the crew compartment wall. A comparison of the result obtained when the shield was required to meet the design-dose criteria for this situation and of the result obtained when the shield material was uniformly distributed over the wall area, is shown in Table B-1.

Table B-1

COMPARISON OF UNIFORM AND SHAPED SHIELDS

Shield Location	Shield Area (cm^2)	Uniform Shield Thickness ($gram/cm^2$)	Uniform Shield Weight (kg)	Shaped Shield Thickness ($gram/cm^2$)	Shaped Shield Weight (kg)
Bottom	3.68×10^5	1.37	504	0.34	125
Side	6.23×10^5	1.37	854	0.84	825
Top	5.47×10^5	1.37	750	1.78	975
Total:	1.54×10^6		2,108		1,625

A weight reduction of 23% is obtained as a result of nonuniform shield material distribution. Even larger savings are possible if more variables (more candidate shield locations) are treated through further subdivision of the shield areas, allowing an even greater fraction of the total shielding to be positioned at hot spots on the compartment wall.

Figure B-2 is a case history of an optimization calculation showing the variation of dose values and shield weight throughout the iterative computations. These data were obtained for the same orbital conditions and vehicle configuration presented in the preceding comparison, except for the existence of a biowell. Therefore, eight candidate shield locations were considered, including three locations at the vehicle's wall structure and five internal locations comprising the biowell. Three critical organ dose criteria were specified for this problem. These criteria are the total dose received by each organ at three time-weighted astronaut stations within the vehicle

The on-board isotope power system was also treated. Only direct neutron and gamma radiation were calculated. As mentioned previously, initial

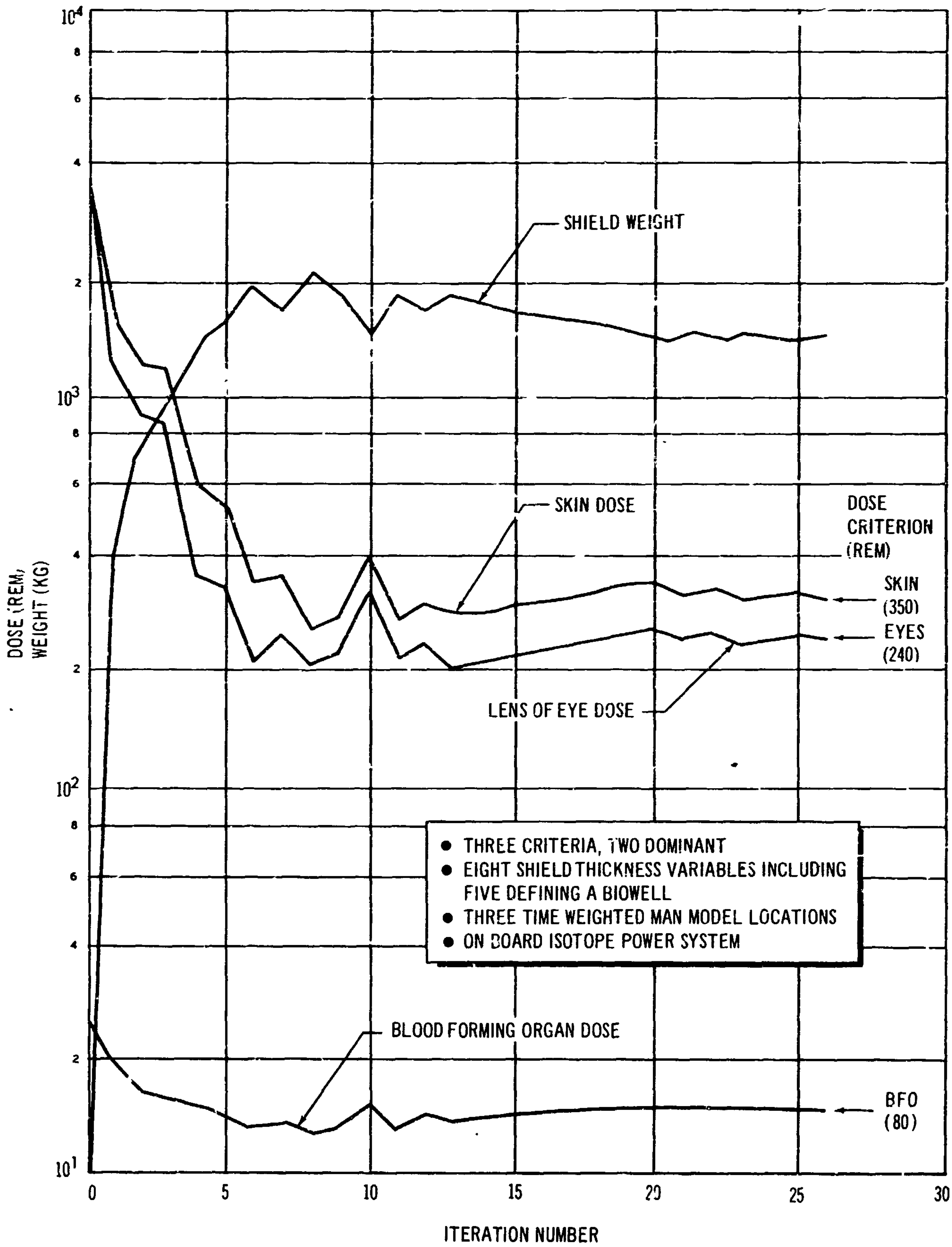


Figure B-2. Case History of a Shield Optimization Problem computations utilizing SWORD found the single-scattered fluxes to be negligible. In fact, the shielding specified for the isotropic source was sufficiently great that even direct radiation contributed little to mission dose (approximately 10 Rem), and hence, had an insignificant effect on the optimization computations.

In the analysis, the dose criterion imposed on the blood-forming organs was not important; the eye and skin dose criteria were dominant. All final values are influenced by the size of the shield weight increment used for the last several iterations, in this case 55 lb. This value is controlled by the magnitude of the initial weight increment established at the somewhat large value of 880 lb to reduce the number of iterations for presentation purposes.

B.5 BASIC RADIATION DATA

Tables B-2 and B-6 summarize the averaged mission radiation energy spectra referenced in Section 6.1 of this report. These data were obtained from the OGRE computer program described in Reference 1.

Figures B-3 through B-8 describe the conversion of the above flux data into dose rates as a function of shield density. These curves were obtained by the CHARGE program described in Reference 16. Figures B-3 through B-8 are inputs to the SWORD program. While the attenuation data are given for a polyethylene shield material, the bremsstrahlung production computations were performed assuming an initial laminate of aluminum corresponding to outer-vehicle structure.

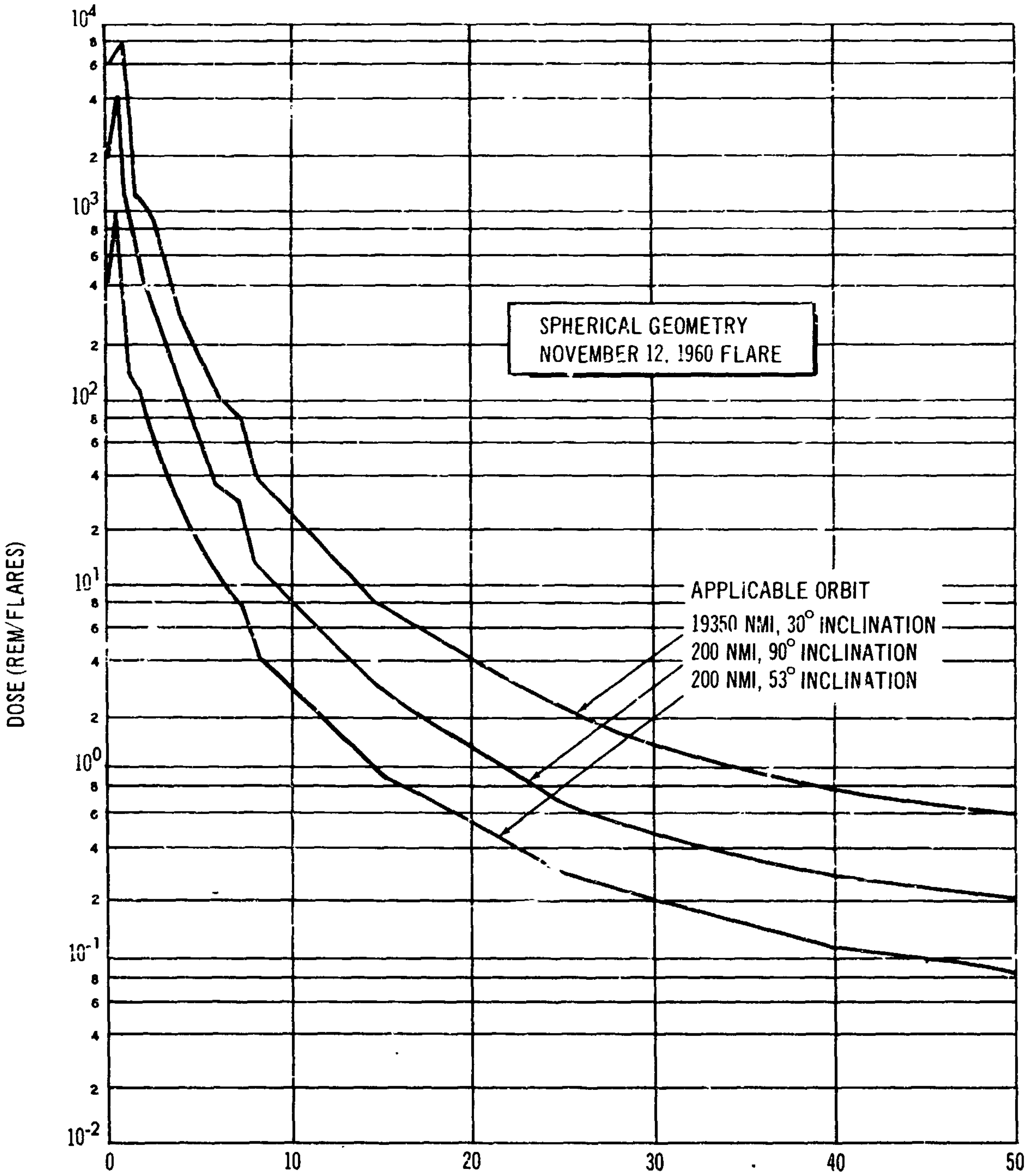


Figure B-3. Basic Dose Attenuation Data for a Solar Flare

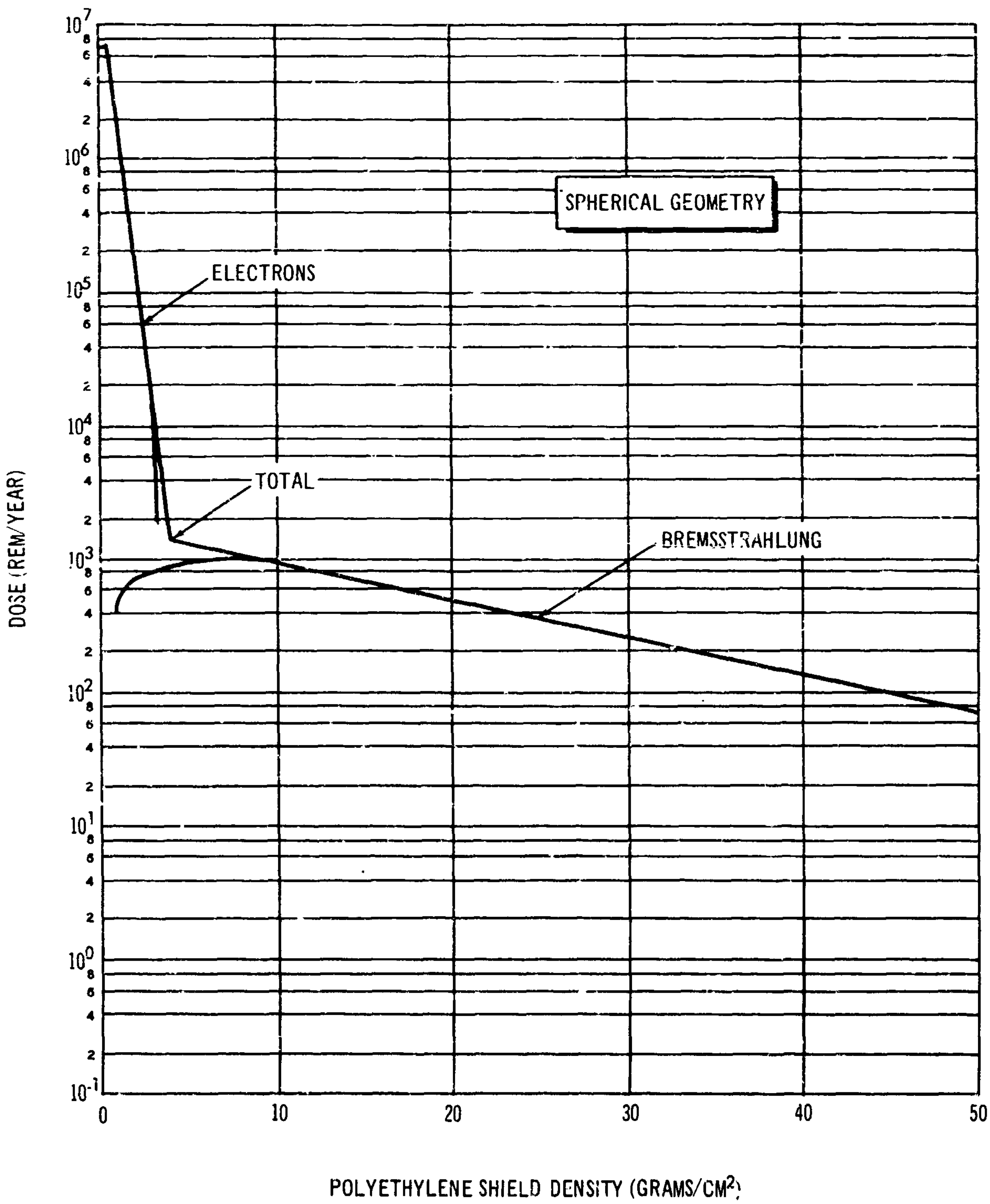


Figure B-4. Basic Dose Attenuation Data for Trapped Radiation – 19,350 nmi, 30° Inclination

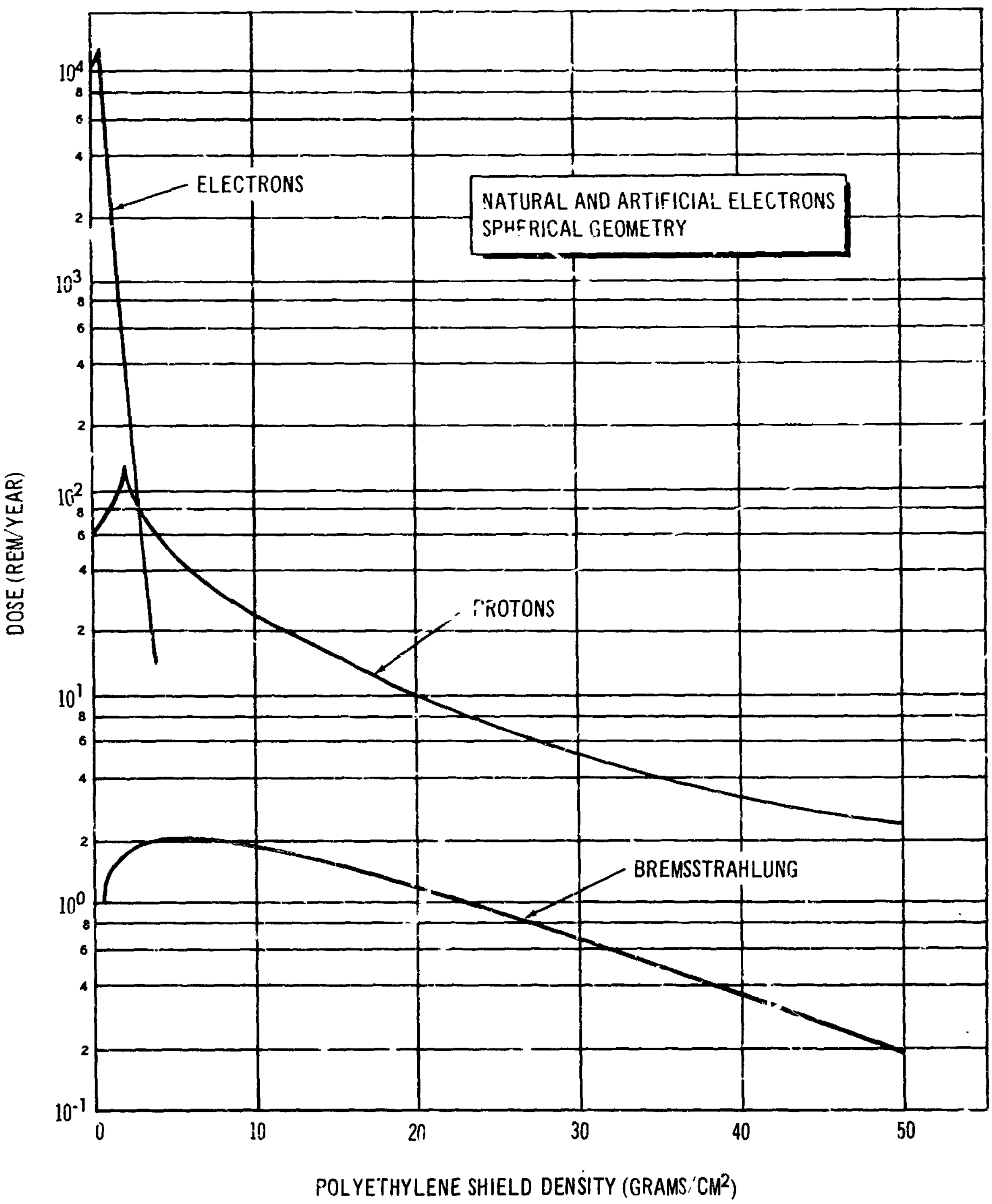


Figure B-5. Basic Dose Attenuation Data for Trapped Radiation – 200 nmi, 53° Inclination, Solar Minimum (1974)

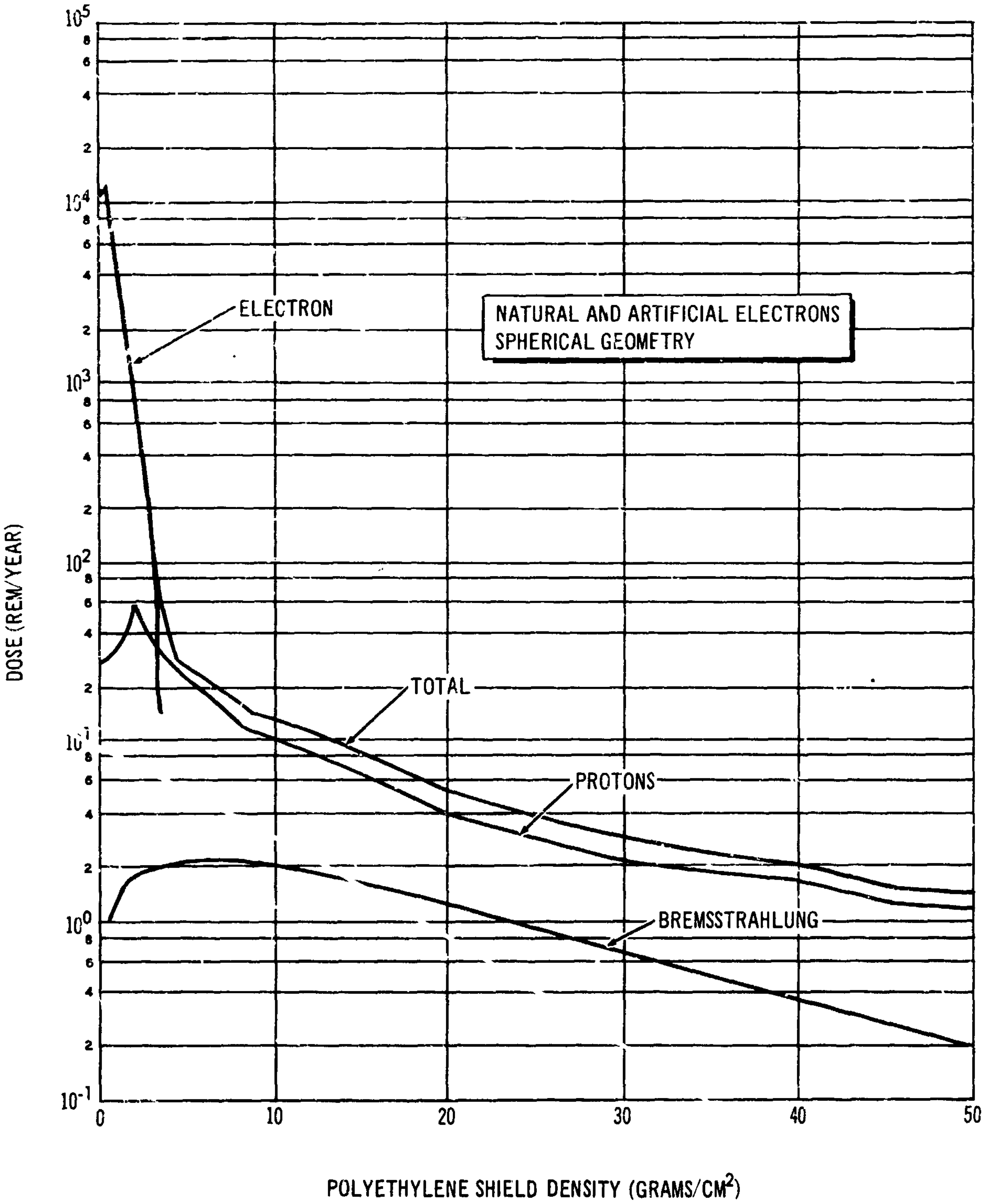


Figure B-6. Basic Dose Attenuation Data for Trapped Radiation – Solar Minimum (1963)
200 nmi, 53° Inclination

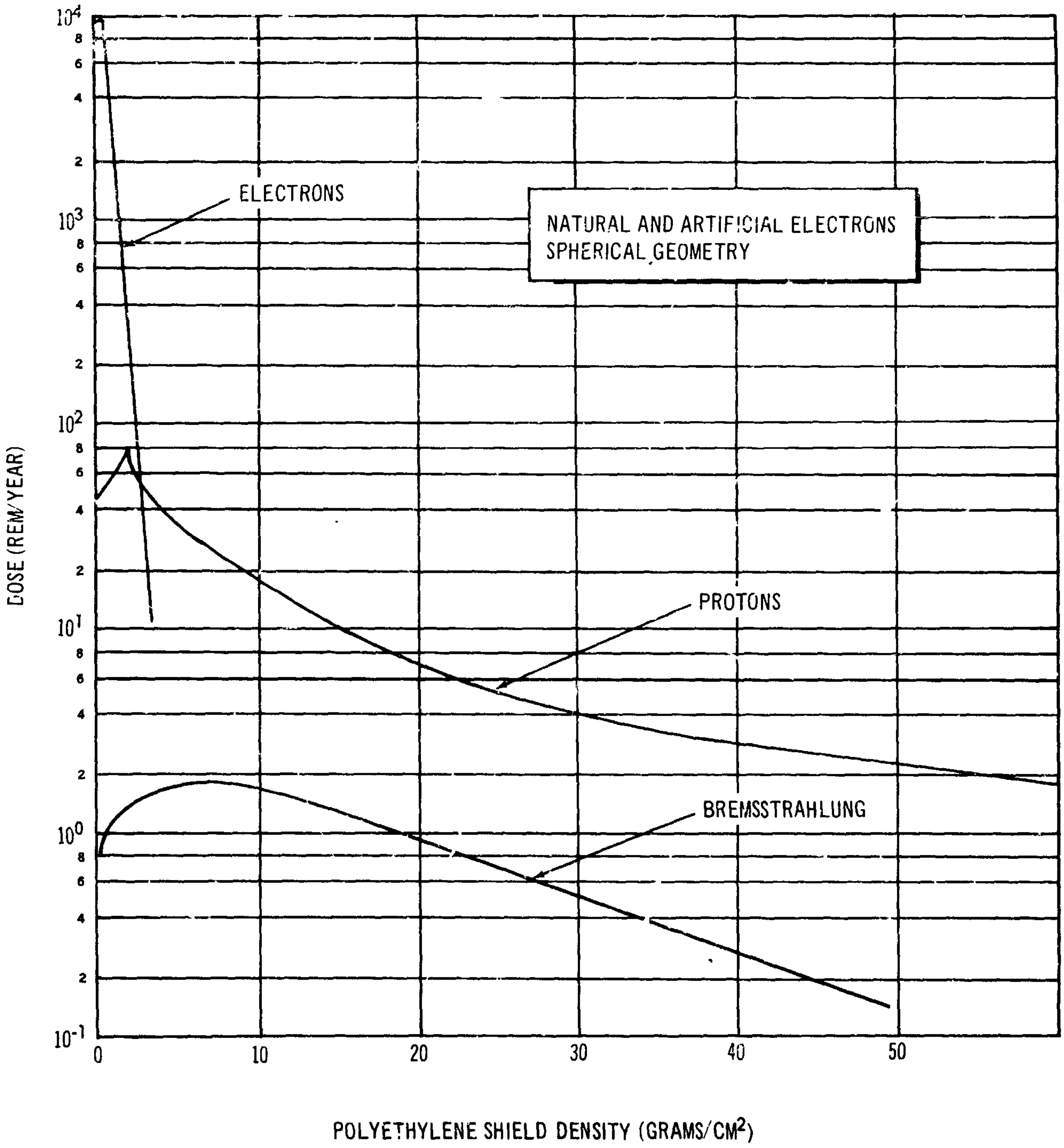


Figure B-7. Basic Dose Attenuation Data for Trapped Radiation – 200 nmi, 90° Inclination, Solar Minimum (1974)

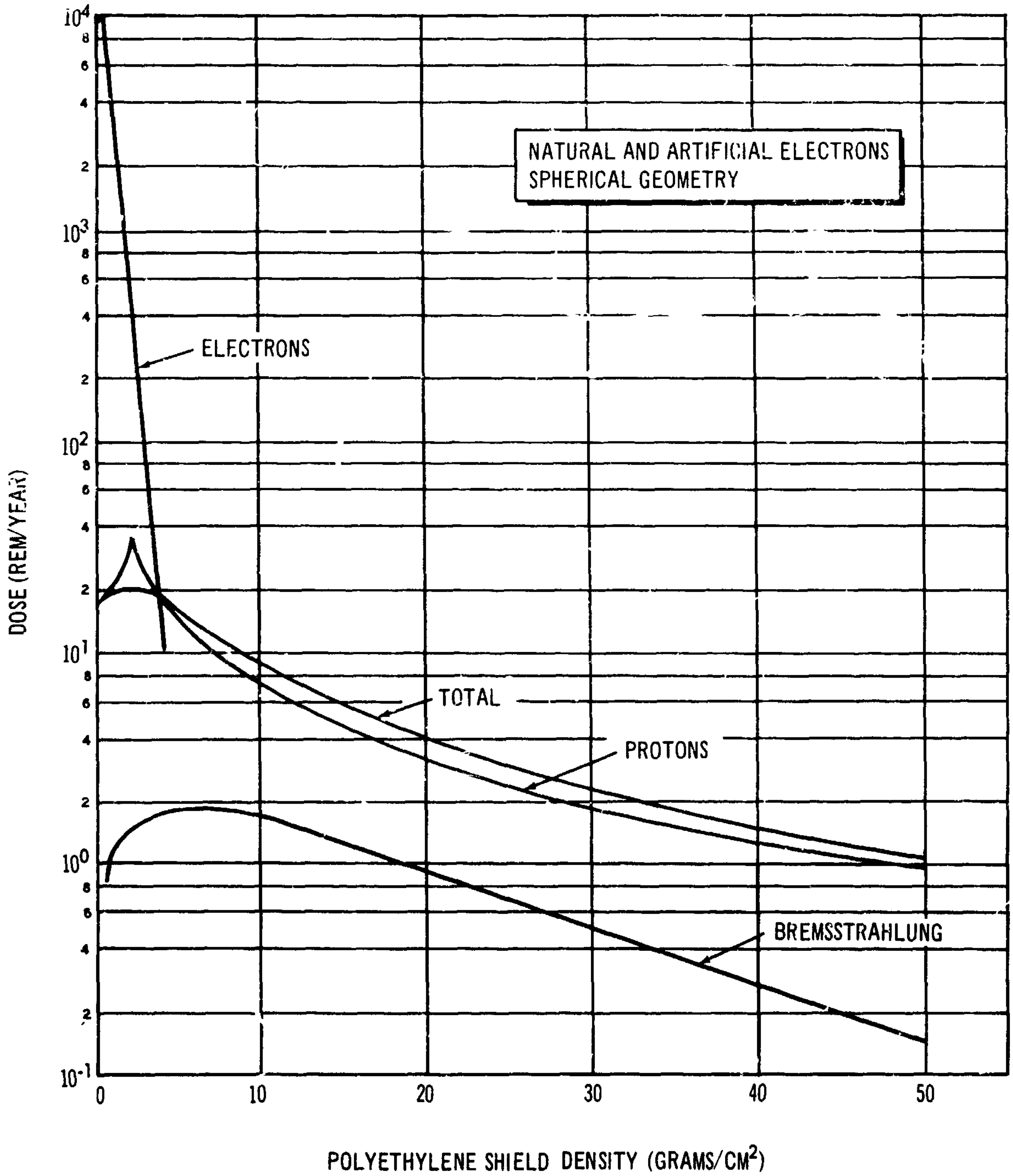


Figure B-8. Basic Dose Attenuation Data for Trapped Radiation – 200 nmi, 90° Inclination, Solar Maximum (1968)

Table B-2

SOLAR COSMIC PROTON SPECTRA FOR 200 nm ORBITS

(November 12, 1960 Flare Model)

E MeV	53^{o} P/cm^2-MeV	90^{o} P/cm^2-MeV
20	1.3210E 08	5.5952E 08
30	4.3489E 07	1.6914E 08
50	1.0803E 07	3.7404E 07
70	4.1080E 06	1.6948E 07
100	8.2965E 05	2.6692E 06
200	3.2981E 04	8.5968E 04
300	5.0606E 03	1.2200E 04
500	2.6988E 03	5.8052E 03
700	4.9588E 02	9.7285E 02
1,000	8.4768E 01	1.4691E 02
2,000	2.7568E 00	3.7835E 00
3,000	3.6417E -01	4.6113E -01
5,000	2.7077E -02	3.1606E -02
Total flux (P/cm^2/Flare)	1.420×10^{9}	5.572×10^{9}

Table B-3

RADIATION SPECTRA FOR SYNCHRONOUS ORBIT

(19, 328 nmi, 30° inclination)

Solar Cosmic Proton Spectra (November 12, 1960 Flare Model)		Planetary Trapped Electron Spectra	
$\overline{E}$ (MeV)	P/cm^2-MeV	$\overline{E}$ (MeV)	E/cm^2-year-MeV
20	2.200E 09	0.75	4.611 E13
30	6.518E 08	1.25	2.320 E13
50	1.408E 08	1.75	1 168 E13
70	5.131E 07	2.25	5.879 E12
100	9.565E 06	2.75	2.960 E12
200	2.989E 05	3.25	1.491 E12
300	3.936E 04	3.75	7.510 E11
500	1.756E 04	4.25	3.784 E11
700	2.854E 03	4.25	3.784 E11
1,000	4.159E 02	4.75	1.907 E11
2,000	9.850E 00	5.25	8.727 E10
3,000	1.103E 00	5.75	5.042 E10
5,000	6.992E 02	6.25	2.812 E10
		6.75	1.406 E10
		7.25	7.020 E9
		7.75	3.355 E9
Total flux (P/cm^2/Flare) 2.100 E10		Total flux (E/cm^2-year) 4.642 E13 0.5<E<3 MeV	

Table B-4

PLANETARY TRAPPED ELECTRON SPECTRA FOR 200 nmi ORBITS (Natural and Artificial)

		Solar Min. (1963.5)		Solar Max. (1968*)	
Ē (Mev)	Δ E (Mev)	53° Orbit E/cm^2-year-Mev	90° Orbit (E/cm^2-year-Mev)	53° Orbit (E/cm^2-year-Mev)	90° Orbit (E/cm^2-year-Mev)
0.75	0.50	2.808E 12	1.979E 12	4.068E 11	3.494E 11
1.25	0.50	1.702E 12	1.179E 12	2.344E 11	1.875E 11
1.75	0.50	1.035E 12	7.099E 11	1.362E 11	1.041E 11
2.25	0.50	6.311E 11	4.306E 11	7.987E 10	5.934E 10
2.75	0.50	3.8[illegible]9E 11	2.625E 11	4.721E 10	3.454E 10
3.25	0.50	2.365E 11	1.608E 11	2.811E 10	2.043E 10
3.75	0.50	1.452E 11	9.876E 10	1.687E 10	1.223E 10
4.25	0.50	8.938E 10	6.085E 10	1.020E 10	7.395E 9
4.75	0.50	5.513E 10	3.759E 10	6.208E 9	4.508E 9
5.25	0.50	4.05 E 10	2 784E 10	4.578E 9	3.321E 9
5.75	0.50	2.342E 10	1.608E 10	2.644E 9	1.919E 9
6.25	0.50	1.306E 10	8.969E 9	1.475E 9	1.070E 9
6.75	0.50	6.530E 9	4.485E 9	7.373E 8	5.350E 8
7.25	0.50	3.261E 9	2.239E 9	3.681E 8	2.672E 8
7.75	0.50	1.558E 9	1.070E 9	1.759E 8	1.277E 8
Total flux, (0.5 < E < 8 Mev) E/cm^2-year, No decay		3.589E 12	2.490E 12	4.880E 11	3.934E 11
Total flux, decayed **				8.280E 10	6.670E 10

* 1963.5 data corrected to 1968 atmospheric conditions.
** 1963.5 data decayed by factor of 5.9 to 1968 equivalent; no decay between 1968 and 1974.

Table B-5

PLANETARY TRAPPED PROTON SPECTRA FOR 200 nmi ORBITS

$\overline{E}$ (MeV)	Δ E (MeV)	Solar Max. (1968) 53° Orbit P/cm^2-year-MeV	Solar Max. (1968) 90° Orbit P/cm^2-year-MeV	Solar Min. (1974) 53° Orbit P/cm^2-year-MeV	Solar Min. (1974) 53° Orbit P/cm^2-year-MeV
45	10	3.929E 06	2.235E 06	9.079E 06	5.400E 06
55	10	2.518E 06	1.472E 06	6.370E 06	3.914E 06
65	10	1.855E 06	1.122E 06	4.866E 06	3.074E 06
75	10	1.438E 06	8.930E 05	3.855E 06	2.487E 06
85	10	1.151E 06	7.297E 05	3.127E 06	2.050E 06
95	10	9.409E 05	6.073E 05	2.580E 06	1.714E 06
125	50	5.611E 05	3.772E 05	1.553E 06	1.062E 06
175	50	2.815E 05	1.986E 05	7.647E 05	5.397E 05
225	50	1.607E 05	1.172E 05	4.167E 05	3.011E 05
275	50	1.001E 05	7.461E 04	2.433E 05	1.790E 05
325	50	6.644E 04	5.023E 04	1.498E 05	1.117E 05
375	50	4.622E 04	3.527E 04	9.625E 04	7.250E 04
425	50	3.329E 04	2.558E 04	6.411E 04	4.866E 04
475	50	2.462E 04	1.901E 04	4.401E 04	3.360E 04
525	50	1.858E 04	1.441E 04	3.099E 04	2.378E 04
575	50	1.424E 04	1.108E 04	2.230E 04	1.718E 04
625	50	1.106E 04	8.626E 03	1.635E 04	1.264E 04
675	50	8.674E 03	6.781E 03	1.218E 04	9.454E 03
Total flux (P/cm^2-year) 40 < E < 700 MeV		1.926E 08	1.330E 08	4.8096E 08	3.2465E 08

Table B-6

NATURAL ELECTRON SPECTRA FOR 200 nmi ORBITS

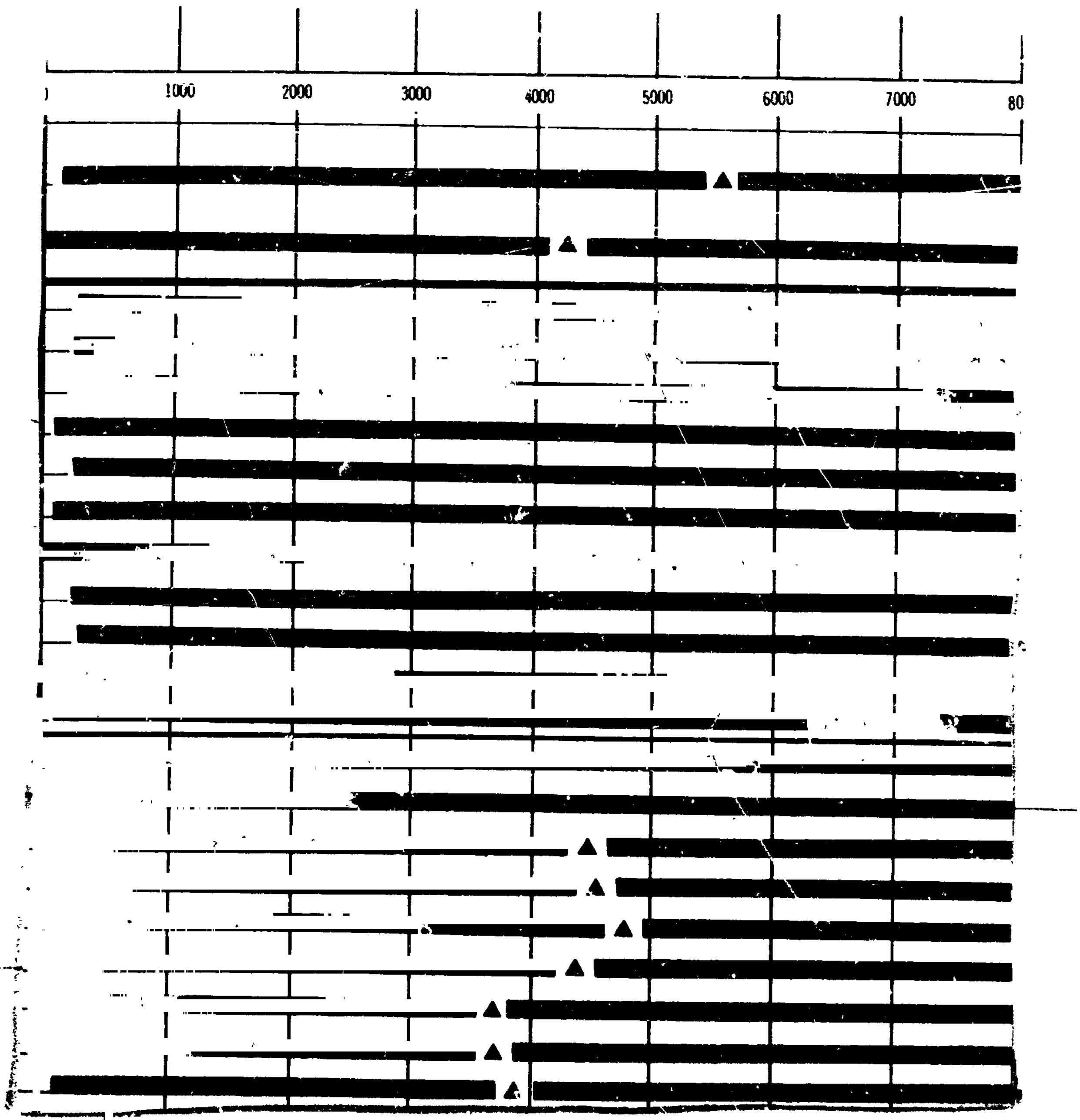
Period	Electron Spectrum (Electron/cm^2-year-MeV) 53° Inclination	90° Inclination
Solar max. 1968	$N_{(E)} = 2.44\times10^{13}e^{-6.25E}$ (0.16<E<5.0 MeV)	$N_{(E)} = 1.967\times10^{13}e^{-6.25E}$ 0.16<E<5.0 MeV
Solar min. 1974	$N_{(E)} = 1.795\times10^{14}e^{-6.25E}$ (0.15<E<5 MeV)	$N_{(E)} = 1.245\times10^{14}e^{-6.25E}$ (0.16<E<5 MeV)

CATEGORY	SPEED EXPERIMENT NUMBER	SOURCE NUMBER	SOURCE	
LIFE SUPPORT SYSTEM & ENVIRONMENT MONITOR	2001	IIID-16		EVALUATION O
	2002	IIIA-11		IONIZATION-R
BIOMEDICAL ASSESSMENT	20031	IIIA-1	DATA BANK	EFFECTS OF Z
	20032	IIIA 1	DATA BANK	EFFECTS OF Z
	20033	IIIA 1	DATA BANK	EFFECTS OF Z
	20034	IIIA 1	DATA BANK	EFFECTS OF Z
	20035	IIIA-1	DATA BANK	EFFECTS OF Z
	20041	IIIA 2	DATA BANK	CONDITIONING
	20042	IIIA 2	DATA BANK	CONDITIONING
	20043	IIIA 2	DATA BANK	CONDITIONING
	20044	IIIA 2	DATA BANK	CONDITIONING
	20045	IIIA 2	DATA BANK	CONDITIONING
	2005	IIIB 13	DATA BANK	RESPIRATORY
	20061	IIIA 5	DATA BANK	BEHAVIORAL
	20062	IIIA 5	DATA BANK	BEHAVIORAL
	20063	IIIA-5	DATA BANK	BEHAVIORAL
	20064	IIIA-5	DATA BANK	BEHAVIORAL
	20065	IIIA 5	DATA BANK	BEHAVIORAL
	20066	IIIA-5	DATA BANK	BEHAVIORAL
	20071	IIIA-7	DATA BANK	CREW PERFOR
	20072	IIIA-7	DATA BANK	CREW PERFOR
	20073	IIIA-7	[illegible]	[illegible]

TITLE	PERIOD (HOURS)	DURATION (HOURS/CYCLE)	NUMBER OF CYCLES
F LIFE SUPPORT SYSTEMS	24	1	365
ADIATION MEASUREMENTS	168	1	52
ZERO-GRAVITY ON MAN (CREWMAN NO 1)	24	4	1100
ZERO-GRAVITY ON MAN (CREWMAN NO 2)	24	4	1100
ERO GRAVITY OF MAN (CREWMAN NO 3)	24	4	1100
ERO-GRAVITY ON MAN (CREWMAN NO 4)	24	4	1100
ZERO-GRAVITY ON MAN (CREWMAN NO 5)	24	4	1100
DEVICE EVALUATION (CREWMAN NO 1)	24	1 3	1100
DEVICE EVALUATION (CREWMAN NO 2)	24	1 3	1100
DEVICE EVALUATION (CREWMAN NO 3)	24	1 3	1100
DEVICE EVALUATION (CREWMAN NO 4)	24	1 3	1100
DEVICE EVALUATION (CREWMAN NO 5)	24	1 3	1100
GAS TOXICOLOGY	24	2	365
RESPONSES IN THE ORBITAL ENVIRONMENT (CREWMAN NO 1)	168	6	52
RESPONSES IN THE ORBITAL ENVIRONMENT (CREWMAN NO 2)	168	6	52
RESPONSES IN THE ORBITAL ENVIRONMENT (CREWMAN NO 3)	168	6	52
RESPONSES IN THE ORBITAL ENVIRONMENT (CREWMAN NO 4)	168	6	52
RESPONSES IN THE ORBITAL ENVIRONMENT (CREWMAN NO 5)	168	6	52
RESPONSES IN THE ORBITAL ENVIRONMENT (CREWMAN NO 6)	168	6	52
RMANCE DURING ORBIT AND RE-ENTRY (CREWMAN NO 1)	720	1.25	12
MANCE DURING ORBIT AND RE-ENTRY (CREWMAN NO. 2)	720	1 25	12
MANCE DURING ORBIT AND RE ENTRY (CREWMAN NO 3)	720	1.25	12

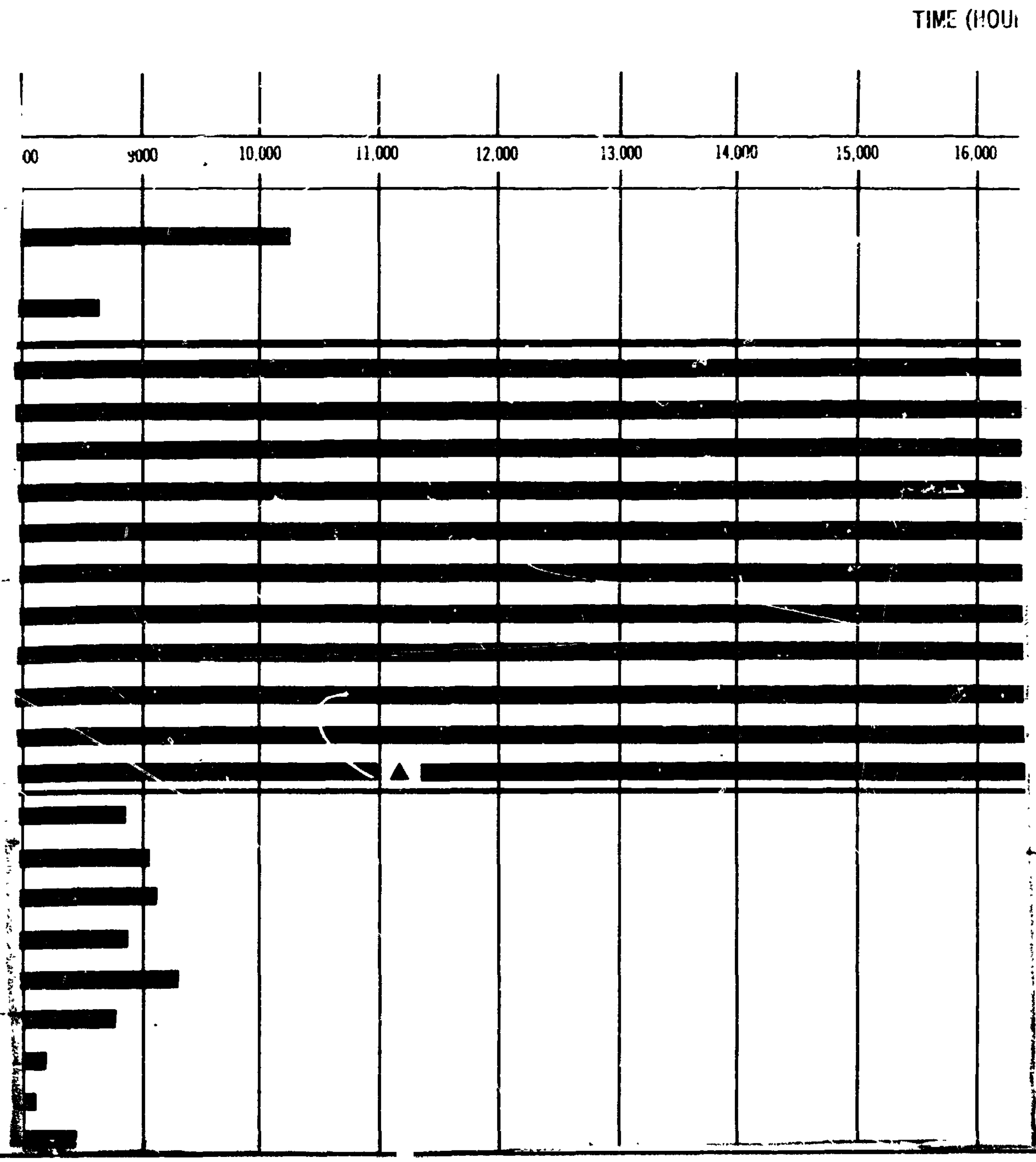
MORL EXI

(6-I

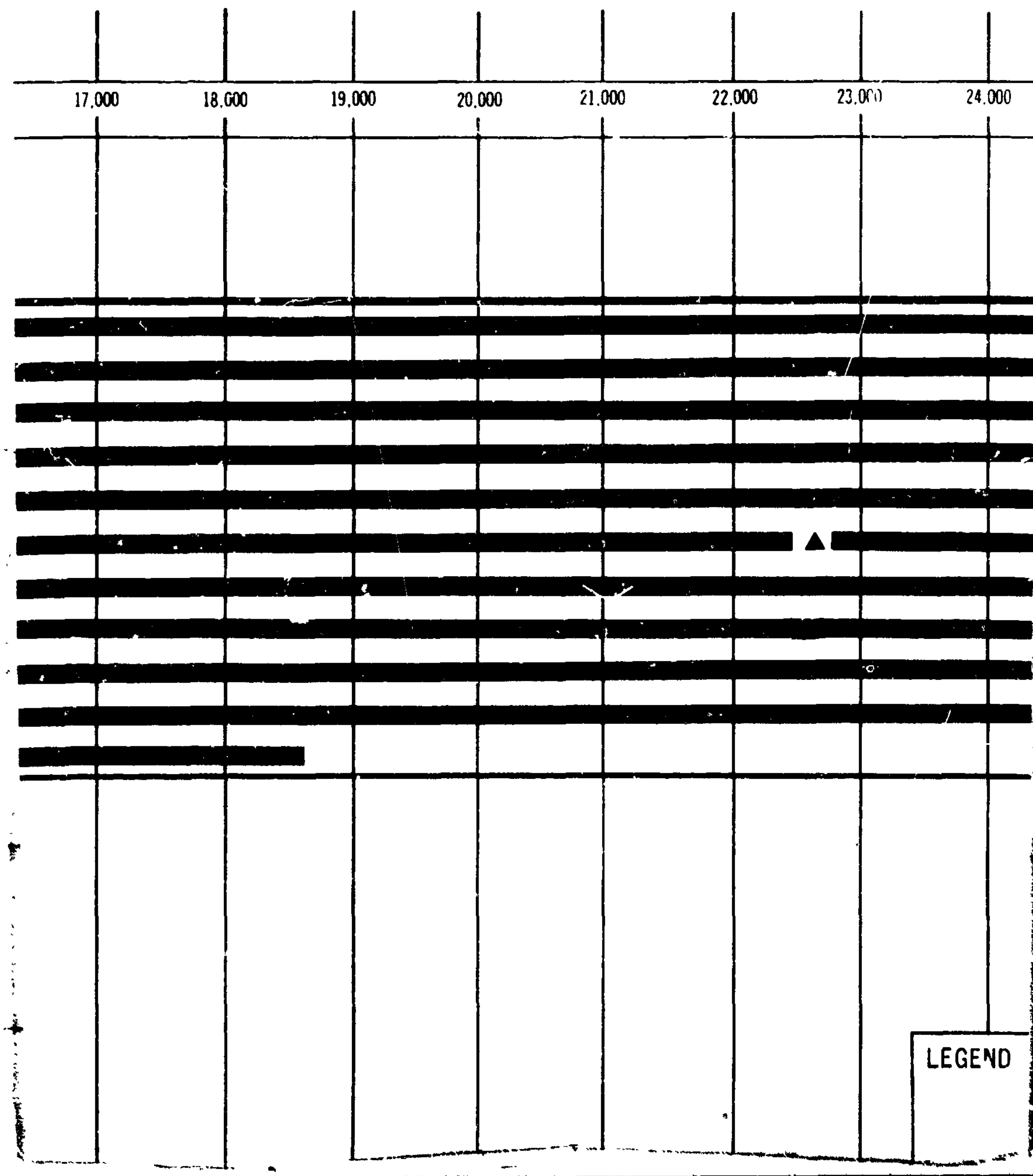


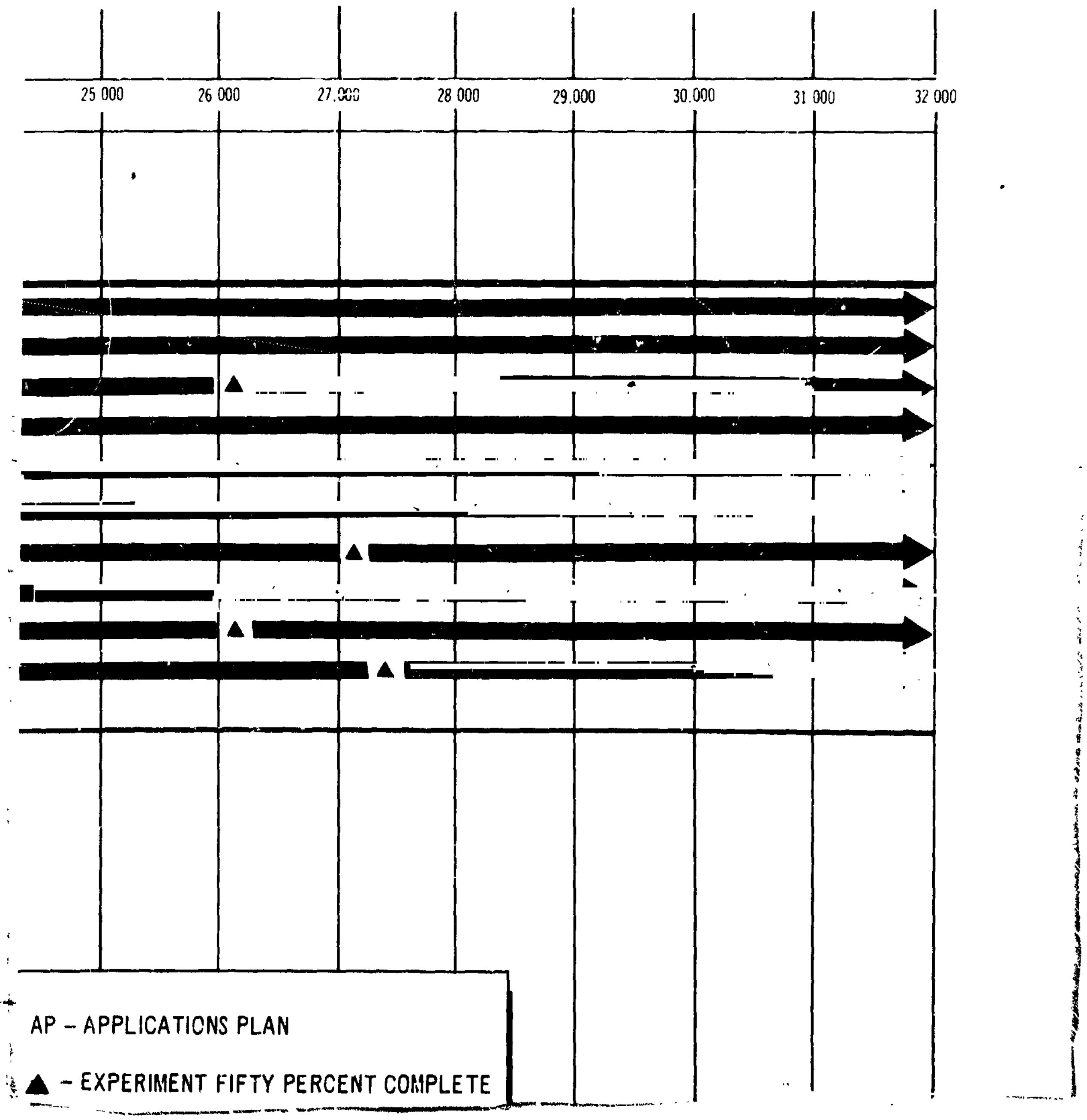
PERIMENT PLAN

MAN LAB)



ꓤS)




25 000
26 000
27.000
28 000
29.000
30.000
31 000
32 000
AP – APPLICATIONS PLAN
▲ – EXPERIMENT FIFTY PERCENT COMPLETE

BEHAVIORAL ASSESSMENT	20074	IIIA-7	DATA BANK	CREW
	20075	IIIA-7	DATA BANK	CREW
	20076	IIIA-7	DATA BANK	CREW
	20081	IIIA-6	DATA BANK	BEHAV
	20082	IIIA-6	DATA BANK	BEHAV
	20083	IIIA-6	DATA BANK	BEHAV
	20084	IIIA-6	DATA BANK	BEHAV
	20085	IIIA-6	DATA BANK	BEHAV
	20086	IIIA-6	DATA BANK	BEHAV
	20091	IIIA-8	DATA BANK	RETEN
	20092	IIIA-8	DATA BANK	RETEN
	20093	IIIA-8	DATA BANK	RETEN
	20094	IIIA-8	DATA BANK	RETEN
	20095	IIIA-8	DATA BANK	RETEN
	20096	IIIA-8	DATA BANK	RETEN
ENVIRONMENT ASSESSMENT	2010	IA-3	DATA BANK	METEO
	2011	IIA-5	DATA BANK	LABOR
	2012	IC-13	DATA BANK	ACTIVA
	2013	IIA-7	DATA BANK	ATMOSF
	2014	IIID-12	DATA BANK	MEASU
	2015	IIID-17	DATA BANK	RESPIR
BIOLOGICAL STUDIES & BASIC MEDICAL RESEARCH	2016	IB-14	DATA BANK	FUNCT
	2017	IB-21	DATA BANK	VESTIB
	20181	IIIA-9	DATA BANK	PLASTI
	20182	IIIA-9	DATA BANK	PLASTI
	20183	IIIA-9	DATA BANK	PLASTI
	20184	IIIA-9	DATA BANK	PLASTI
	20185	IIIA-9	DATA BANK	PLASTI
	20186	IIIA-9	DATA BANK	PLASTI
	20191	IIIA-3	DATA BANK	EVOKED
	20192	IIIA-3	DATA BANK	EVOKED
	20193	IIIA-3	DATA BANK	EVOKED
	20194	IIIA-3	DATA BANK	EVOKED
	20195	IIIA-3	DATA BANK	EVOKED
	2020	IB-4	DATA BANK	EFFECTS

PERFORMANCE DURING ORBIT AND RE ENTRY (CREWMAN NO 4)	720	1 25	12
PERFORMANCE DURING ORBIT AND RE-ENTRY (CREWMAN NO 5)	720	1 25	12
PERFORMANCE DURING ORBIT AND RE ENTRY (CREWMAN NO 6)	720	1 25	12
IORAL RESPONSES IN THE ORBITAL ENVIRONMENT (CREWMAN NO 1)	24	25	365
IORAL RESPONSES IN THE ORBITAL ENVIRONMENT (CREWMAN NO 2)	24	25	365
IORAL RESPONSES IN THE ORBITAL ENVIRONMENT (CREWMAN NO 3)	24	25	365
IORAL RESPONSES IN THE ORBITAL ENVIRONMENT (CREWMAN NO 4)	24	25	365
IORAL RESPONSES IN THE ORBITAL ENVIRONMENT (CREWMAN NO 5)	24	25	365
IORAL RESPONSES IN THE ORBITAL ENVIRONMENT (CREWMAN NO. 6)	24	25	365
ITION OF SKILLS LEARNED IN ORBITAL ENVIRONMENT (CREWMAN NO 1)	24	3	60
TION OF SKILLS LEARNED IN ORBITAL ENVIRONMENT (CREWMAN NO 2)	24	3	60
TION OF SKILLS LEARNED IN ORBITAL ENVIRONMENT (CREWMAN NO 3)	24	3	60
TION OF SKILLS LEARNED IN ORBITAL ENVIRONMENT (CREWMAN NO 4)	24	3	60
TION OF SKILLS LEARNED IN ORBITAL ENVIRONMENT (CREWMAN NO 5)	24	3	60
TION OF SKILLS LEARNED IN ORBITAL ENVIRONMENT (CREWMAN NO. 6)	24	3	60
ROID PHYSICAL CHARACTERISTICS	720	2	12
ATORY LOCAL EXTERNAL ENVIRONMENT	168	2	52
TION MEASUREMENTS OF SELECTED MATERIALS	2160	4	4
PHERIC DRAG MEASUREMENTS	720	1	12
REMENT OF NOISE, VIBRATION AND DYNAMIC DAMPING FACTOR IN SPACECRAFT	96	4	10
ED GASES VENTILATION	24	.2	365
ION AND DYSFUNCTION OF THE GRAVITY-SENSITIVE ORGAN IN ZERO G ENVIR	24	5	90
ULAR NERVE ACTIVITY AT VARIOUS G-LOADS	24	2 5	90
CITY IN HUMAN SENSORIMOTOR CONTROL (CREWMAN NO. 1)	72	3	120
CITY IN HUMAN SENSORIMOTOR CONTROL (CREWMAN NO. 2)	72	3	120
CITY IN HUMAN SENSORIMOTOR CONTROL (CREWMAN NO. 3)	72	3	120
CITY IN HUMAN SENSORIMOTOR CONTROL (CREWMAN NO. 4)	72	3	120
CITY IN HUMAN SENSORIMOTOR CONTROL (CREWMAN NO 5)	72	3	120
CITY IN HUMAN SENSORIMOTOR CONTROL (CREWMAN NO 6)	72	3	120
ELECTROMYOGRAPHY (CREWMAN NO. 1)	360	3	24
ELECTROMYOGRAPHY (CREWMAN NO. 2)	360	3	24
ELECTROMYOGRAPHY (CREWMAN NO. 3)	360	3	24
ELECTROMYOGRAPHY (CREWMAN NO 4)	360	3	24
ELECTROMYOGRAPHY (CREWMAN NO. 5)	360	3	24
S OF ZERO G ON EMBRYOLOGICAL DEVELOPMENT	24	.5	38

8-48

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]
[redacted]
[redacted]
[redacted] ▲ [redacted]
[redacted]
[redacted]
[redacted]

[redacted]

– EXPERIMENT ACTIVITY PERIOD

	2021	IB 5	DATA BANK	ZER_ G
	2022	IB 6	DATA BANK	HIGH VA
	2023	IB 7	DATA BANK	BIOLOGI
	2024	IB 8	DATA BANK	WEIGHTL
	2025	IB 9	DATA BANK	WEIGHTL
	2026	IB 10	DATA BANK	BOTANI
	2027	IB 11	DATA BANK	ANIMAL
SUBSYSTEM & COMPONENT EVALUATION	2028	IIID 24	DATA BANK	BALLIST
	2029	IIIB-19	DATA BANK	GRAVITY
	2030	IIIB-20	DATA BANK	EVALUA
	2031	IIIB-14	DATA BANK	OXYGEN
	2032	IIIB-8	DATA BANK	ELECTR
	2033	IIID-13	DATA BANK	CONTROL
	2034	IIID-14	DATA BANK	REACTIO
	2035	IIID 15	DATA BANK	STABILIZ
	2036	IIIB 21	DATA BANK	RADIOISO
	2037	IB 23	DATA BANK	PARTICU
	2038	IIIB 6	DATA BANK	SOLAR A
	2039	IIIB 1	DATA BANK	SPACE E
	2040	IIIB 2	DATA BANK	METEOR
	2041	IC 10	DATA BANK	JET FLO
	2042	IIIB 4	DATA BANK	COLD WE
	2043	IIID 2	DATA BANK	EVALUAT
	2044	IIIB 3	DATA BANK	FATIGUE
	2045	IC 6	DATA BANK	CRYSTAL
	2046	IIIB-16	DATA BANK	ATMOSPH
	101	101	AP	INSTALL
	1	1	AP	LUBRICA
	201	201	AP	ASSEMBL
	202	202	AP	BORESIGH
	103	103	AP	INSTALL
	$\boxed{3}$	3	AP	ANTENNA
	104	104	AP	INSTALL

?AVITY AND RADIATION EFFECTS ON THE FLOUR BEETLE	24	5	30
..UM RADIATION AND ZERO GRAVITY ON BACTERIA	24	2 5	15
..L STUDIES OF RODENTS IN SPACE ENVIRONMENT	24	4	90
.ESSNESS ON IMMUNE DEFENSES AGAINST PATHOGENIC AGENTS	168	3	4
.ESSNESS ON DIVIDING HUMAN CELLS IN CULTURE	240	4	6
;AL STUDIES OF PLANTS IN THE ORB ENV	24	5	42
ADJUSTMENT TO VARIOUS DEGREES OF GRAVITATIONAL FORCE	240	1	9
..CARDIOGRAPH AND VIBROCARDIOGRAPH EVALUATION	168	1 5	12
..RADIENT COMPONENTS AND TECHNIQUES	24	4	4
..ON OF EXTREMELY LOW RANGE (10^{-8} TO 10^{-11}g) ACCELEROMETERS	24	1	1
RECOVERY SYSTEM	48	4	20
, OPTICAL TECHNIQUES AND EQUIPMENT	96	1 5	22
. SYSTEM EVALUATION - INTERNAL COMPONENTS STABILIZATION	720	1 2	3
N CONTROL COMPONENTS	270	2 5	3
'ATION AND CONTROL SYSTEMS EVALUATION	24	4	1
..OPE - THERMOELECTRIC POWER SYSTEM INTEGRATION	24	1 5	90
.ATE RADIATION ON SELECTED ORGANIC LIVING AND NONLIVING MAT'LS	24	2 5	365
BSORPTIVITY AND THERMAL EMISSIVITY	48	1	.32
VIRONMENT ON MATERIALS AND SURFACES	720	2	10
IIC PENETRA ION OF MATERIALS	7176	5	2
N IN A VACUUM	24	4	5
LDING OF METALS IN SPACE	168	2	52
ION OF SELF SEALING STRUCTURES	2160	4	4
TESTS OF MATERIALS	48	1	100
LIZATION STUDIES	360	2	18
ERE AND MATERIALS EFFECTS ON LASER OPERATION	24	4	20
BEARINGS	4	4	2
TION BEARINGS	96	36	30
Y REPAIR - ANTENNA	4	4	3
T & ALIGNMENT ANTENNA	4	4	4
ANTENNA	4	4	3
DYNAMICS	½	½	6
MATERIALS	4	4	1

[redacted] ▲ [redacted]
[redacted] ▲ [redacted]
[redacted] ▲ [redacted]
[redacted] ▲ [redacted]
[redacted] ▲ [redacted]
[redacted] ▲ [redacted]
[redacted]
[redacted] ▲ [redacted]
[redacted]
[redacted] ▲ [redacted]
[redacted] ▲ [redacted]
[redacted] ▲ [redacted]
[redacted] ▲ [redacted]
[redacted]
[redacted] ▲ [redacted]
▲ [redacted]
▲ [redacted]
▲ [redacted]
[redacted]
[redacted]
[redacted] ▲ [redacted]
[redacted] ▲ [redacted]
[redacted] ▲ [redacted]
[redacted] ▲ [redacted]
[redacted] ▲ [redacted]
[redacted]
[redacted] ▲ [redacted]
[redacted]
15
[redacted]
[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

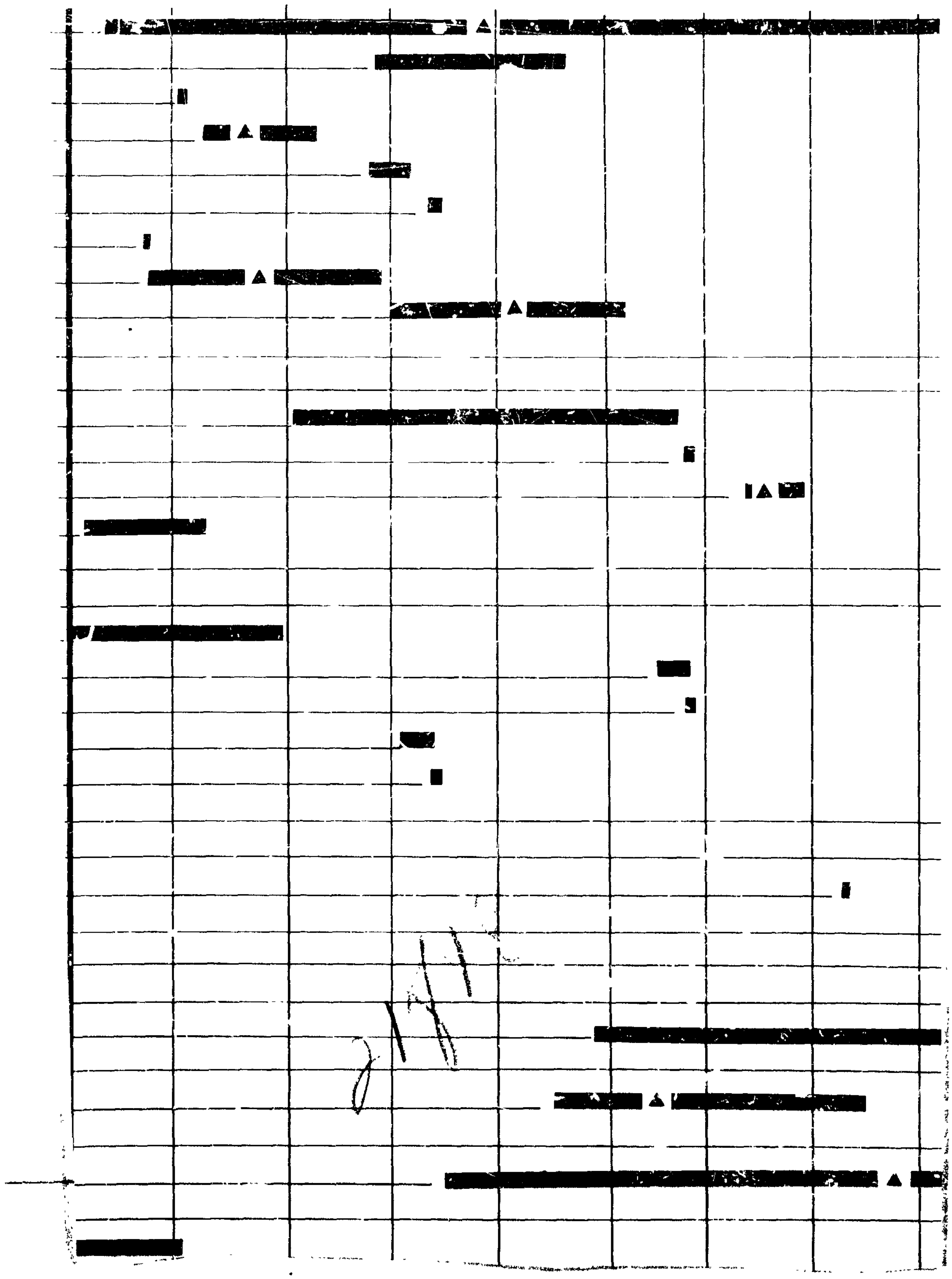
16 of 1

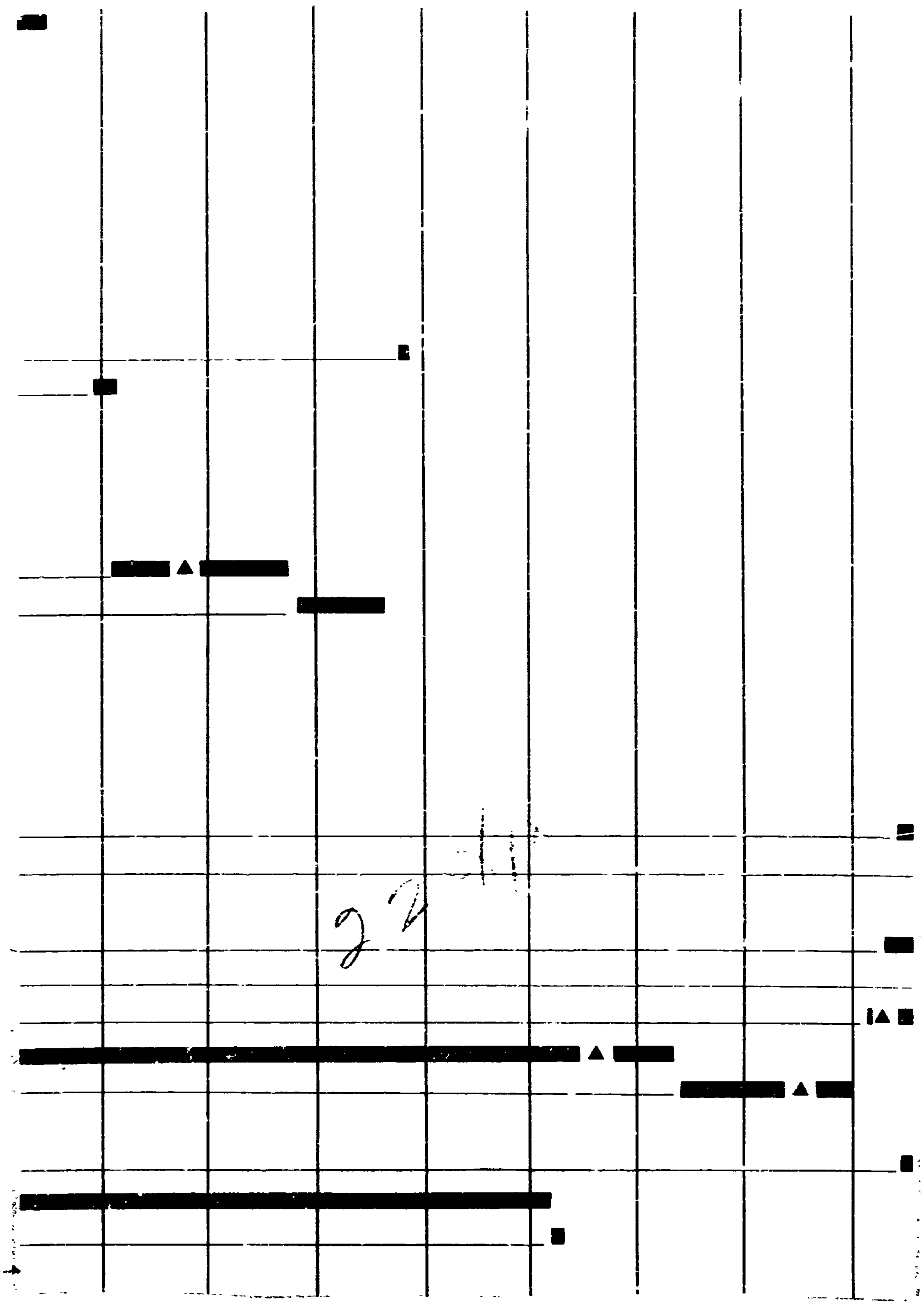
1 of 48

[illegible]

4	4	AP	PLASTIC MAT'LS
5	5	AP	SPECIAL TOOLS
106	106	AP	INSTALL OPTICS
[illegible]	6	AP	PARTICLE IMPIN
[illegible]	71	AP	ASSEMBLY REP
[illegible]	[illegible]	AP	BORESIGHT & AL
115	115	AP	INSTALL CAMER
[illegible]	[illegible]	AP	FILM STABILITY
[illegible]	16	AP	PICTURE RESOL
[illegible]	[illegible]	AP	ASSEMBLY & MAI
[illegible]	[illegible]	AP	TRACKING CAPA
[illegible]	[illegible]	AP	LOCK ON PROCE
[illegible]	1230	AP	INSTALL DRIFTM
230	230	AP	OPERATIONAL C
231	231	AP	TRACKING CAPA
1232	1232	AP	INSTALL RADAR
232	232	AP	PERFORMANCE
233	233	AP	LOCK-ON PROCE
1234	1234	AP	INSTALL CAMER
234	234	AP	CAMERA TEST
1235	1235	AP	INSTALL CAMER
235	235	AP	IMAGE MOTION C
1236	1236	AP	INSTALL RADIOM
236	236	AP	INTEGRATION T
237	237	AP	ABS ACCY MICR
1239	1239	AP	INSTALL RADIOM
239	239	AP	IR RADIOMETER
242	242	AP	POLARIMETER
1243	1243	AP	INSTALL S-BAND
243	243	AP	ALIGN & LOCK-O
244	244	AP	AUTO & MANUAL
246	246	AP	INTEGRATION T
1247	1247	AP	INSTALL LIDAR
247	247	AP	ALIGN & LOCK-
248	248	AP	MANUAL & AUTO

UV SENSITIVITY	720	3	12
	4	4	6
	4	4	1
GEMENT - OPTICS	40	3	10
AIR & LUBE - EXTERNAL OPTICS	4	4	2
IGNMENT - OPTICS	4	4	6
A	3	3	1
	168	2	12
UTION	168	4	12
NTENANCE RADIOMETERS (MICROWAVE & IR)	4	4	6
BILITY	4	4	5
DURE - V H METER	4	4	5
IETER	1	4	2
CAPABILITY OF V H METER	4	4	4
BILITY OF V H METER	4	4	5
PROFILOMETER	4	4	18
EVALUATION OF RADAR PROFILOMETER	4	4	6
L RADAR PROFILOMETER	4	4	5
A	4	4	4
	2	2	5
A	4	4	2
OMPENSATION - CAMERA	2	1	4
METER	4	4	8
EST MICROWAVE RADIOMETER	4	4	20
ROWAVE RADIOMETER	½	½	1
METER	4	4	8
- OPERATIONAL TESTS	8	4	5
TRANSPONDER SATELLITE SYSTEM	3	2	5
) POLARIMETER	4	4	8
ON S-BAND POLARIMETER	4	4	5
- TRACK TRANSPONDER SATELLITE	4	4	5
EST-LASER SYSTEM	4	4	5
	4	4	6
ON LASER	1	1	3
OMATIC TRACKING - TRANSPONDER ANT	3	2	3





[redacted] ▲ [redacted]

[redacted]

[redacted] ▲ [redacted]

[redacted]

[redacted]

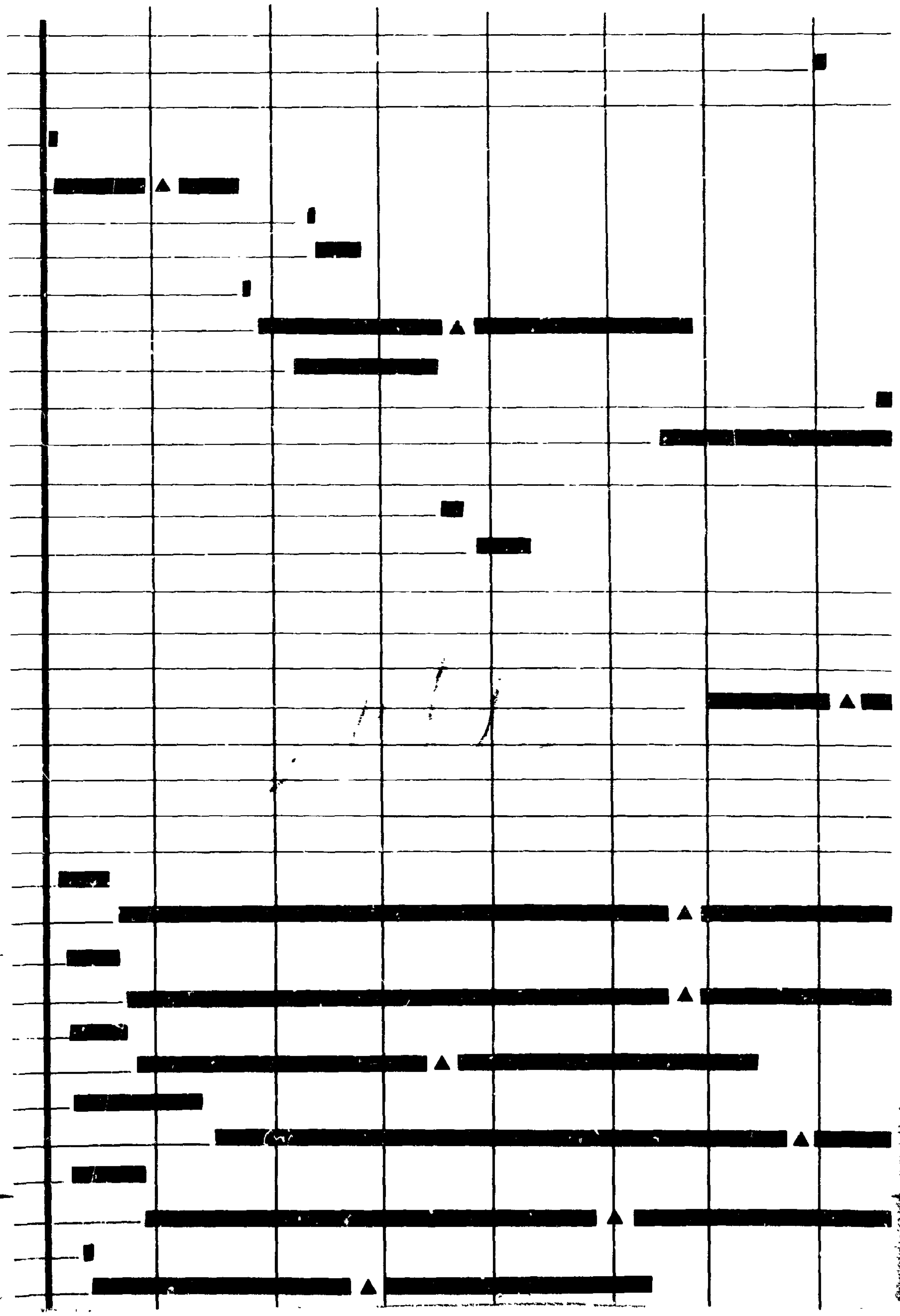
[redacted] ▲ [redacted]

[illegible]

EARTH CENTERED
APPLICATIONS (NETWORK)

252	252	AP	PERF E
253	253	AP	PERF E
254	254	AP	PERF E
121	121	AP	INSTALL
21	21	AP	STABILIT
123	123	AP	INSTALL
23	23	AP	BANDWID
125	125	AP	INSTALL
25	25	AP	ABSOLUT
31	31	AP	ENVIRON
36	36	AP	BORESIGH
138	138	AP	INSTALL
38	38	AP	BASELIN
140	140	AP	INSTALL
40	40	AP	EJECTIO
1226	1226	AP	INSTALL
226	226	AP	PERFORM
227	227	AP	RADAR L
255	255	AP	PERF E
256	256	AP	PERF E
257	257	AP	PERF E
259	259	AP	PERF E
260	260	AP	PERF E
1501	1501	AP	INSTALL
501	501	AP	IR & UV I
1502	1502	AP	INSTALL
502	502	AP	MICROWA
1504	1504	AP	INSTALL
504	504	AP	INTERNA
1510	1510	AP	INSTALL
510	510	AP	LARGE M
1521	1521	AP	INSTALL
521	521	AP	STAR TRA
1523	1523	AP	INSTALL
523	523	AP	DUAL STA

VALUATION OF RADAR	5	1 5	20
/ALUATION OF / H METER	1 5	1	10
/ALUATION OF RADAR PROFILOMETER	1 5	1	10
RADIOMETER	4	4	1
Y OF RADIOMETER (MICROWAVE & IR) IN ENVIRONMENT	1 5	25	200
FILTERS	4	4	1
TH & CHARACTERISTICS OF FILTERS	1 5	25	10
RADIOMETER	4	4	1
E ACCURACY OF IR RADIOMETER	168	3	24
MENT EFFECTS ON TRANSPONDER SATELLITE	4	4	3
HT & ALIGNMENT OF LASER	4	4	2
SATELLITE	4	4	3
E DETERMINATION LASER SATELLITE	3	3	20
SATELLITE	3	3	3
V & RETRIEVAL OF TRANSPONDER SATELLITE	4	4	10
RADAR	4	4	18
MANCE EVALUATION K & C-BAND RADAR	4	4	10
OCK-ON PROCEDURE	2	2	1
/ALUATION OF CAMERA	1 5	5	30
/ALUATION OF MICROWAVE RADIOMETER	1 5	1.5	20
/ALUATION OF IR RADIOMETER	1 5	1.5	30
/AL OF S-BAND POLARIMETER	1.5	1 5	10
/ALUATION OF LIDAR	1.5	1	20
DETECTORS	4	4	2
DETECTORS – SPACE EFFECTS	120	4	73
ANTENNA	4	4	2
VE RAD WINDOW – SPACE EFFECTS	120	4	73
BEARINGS	4	4	2
L BEARINGS	168	3	30
MIRROR	4	4	6
IRRORS – ENVIRON.	120	4	73
STAR TRACKER SENSOR	4	4	2
ACKER SENSOR	480	4	18
DUAL STAR TRACKER	3	3	1
R TRACKER – GYRO STAB	72	.5	60



[redacted]

[redacted]

[redacted]

[redacted]

24 4 '16

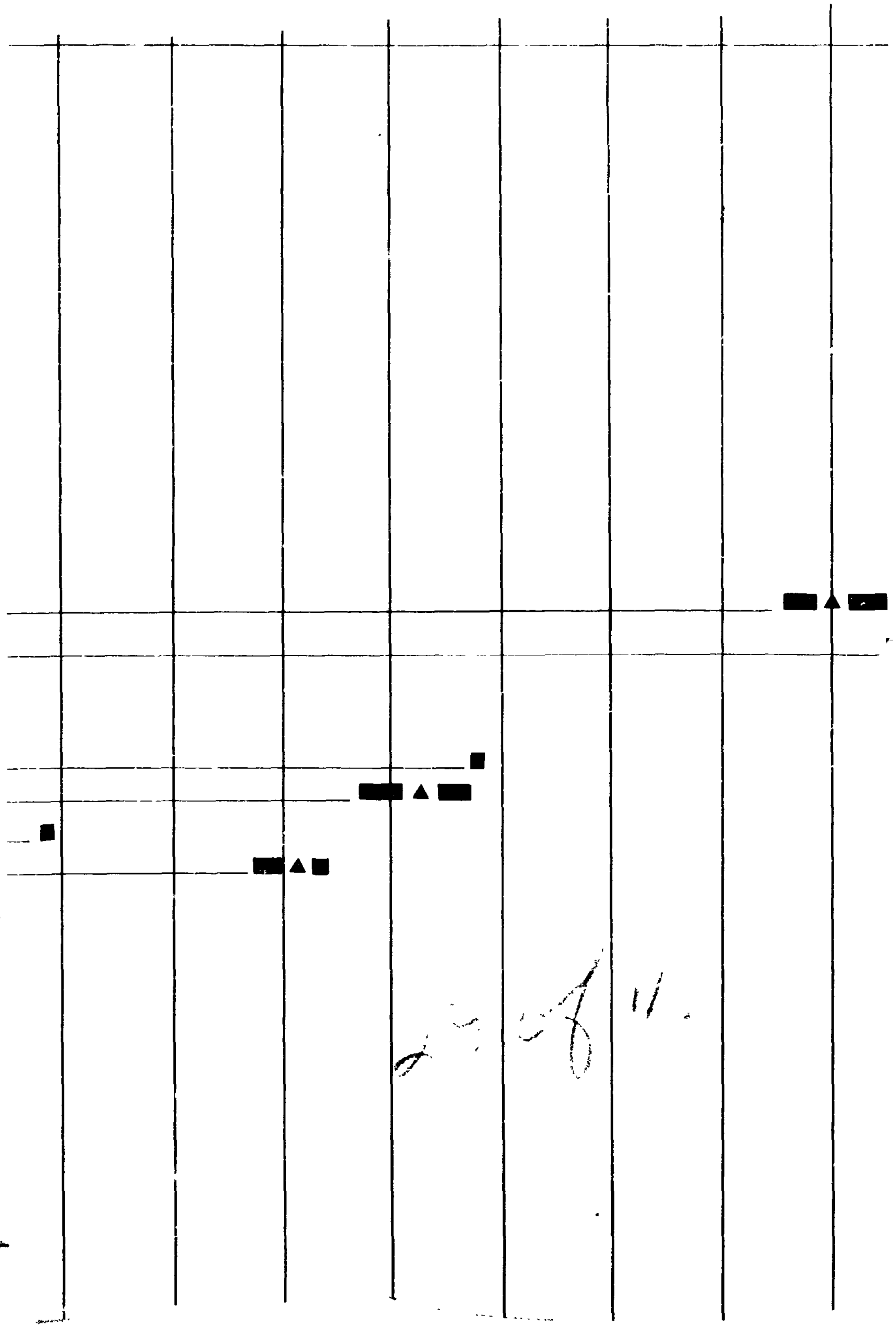
[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

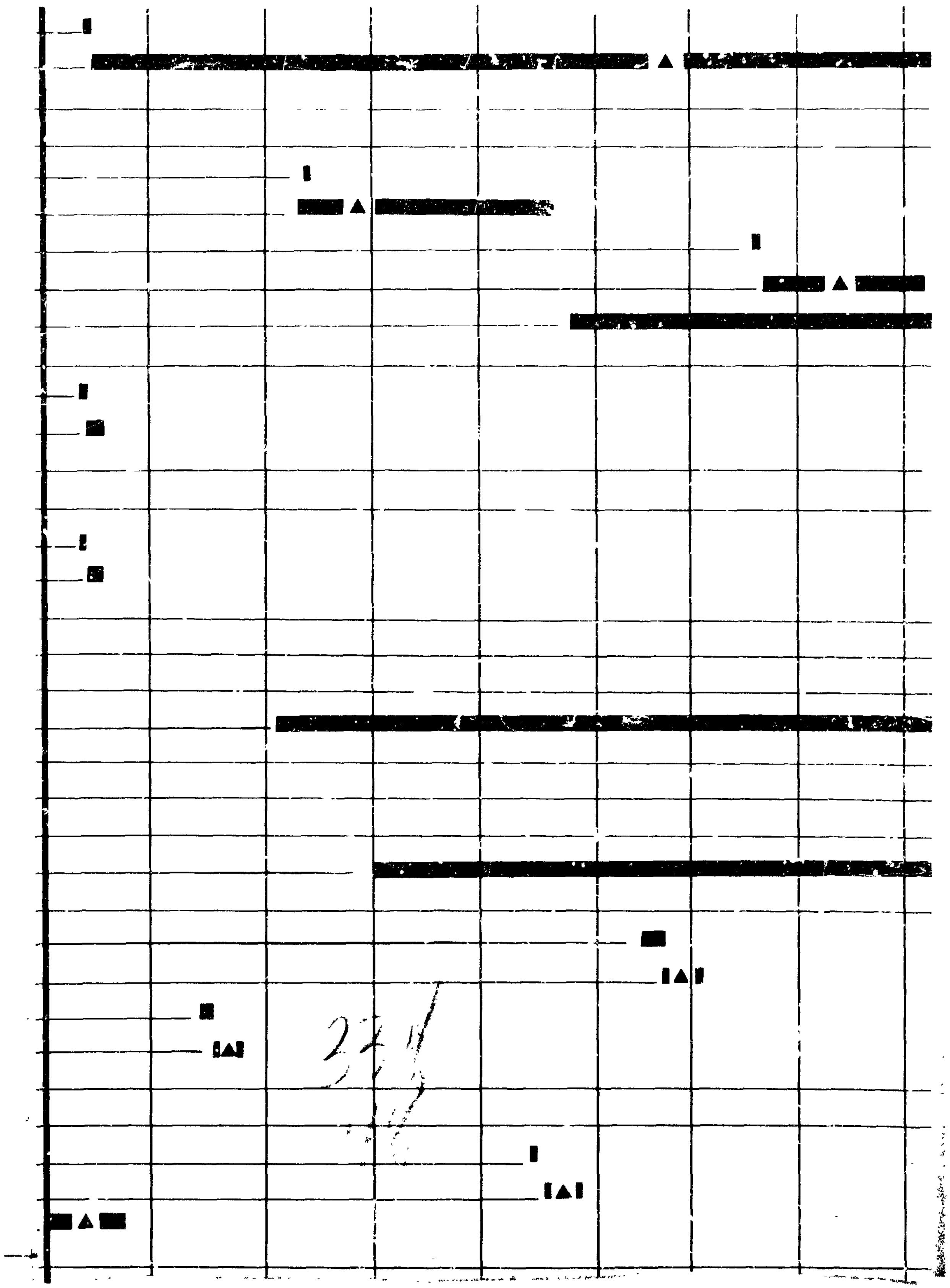


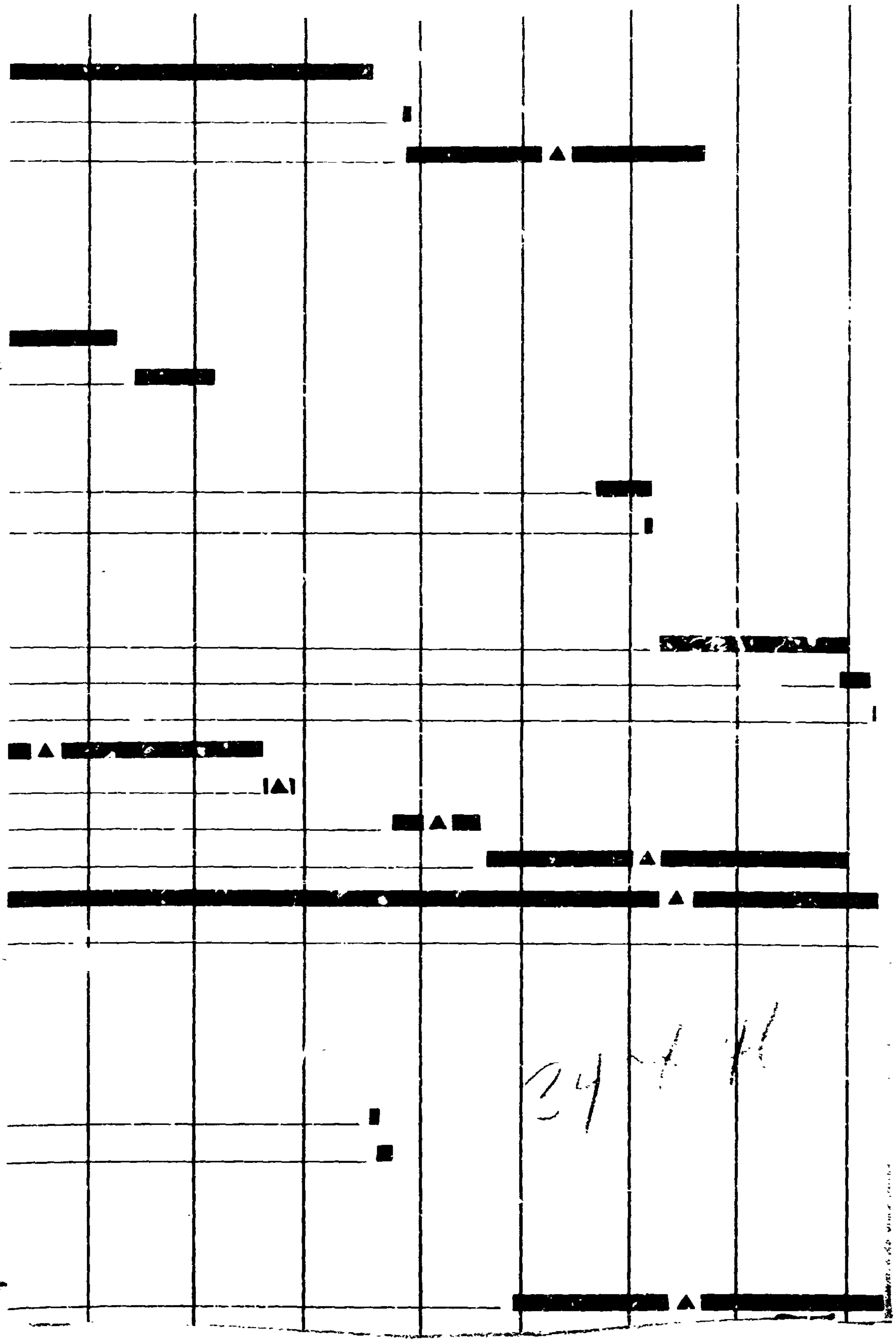
30 6 42

1534	1534	AP	INSTALL DET
534	534	AP	TV DETECTOI
1601	1601	AP	INSTALL DET
601	601	AP	IR DETECTOF
1603	1603	AP	INSTALL PHO
603	603	AP	PMT CHARAC
1604	1604	AP	INSTALL BEA
604	604	AP	LUBE ON GIM
1608	1608	AP	INSTALL OPT
608	608	AP	EVA – OPTIC
1613	1613	AP	INSTALL PHO
613	613	AP	PMT EVALUA
1614	1614	AP	INSTALL MIRF
614	614	AP	ASSY BORESI
1615	1615	AP	INSTALL DISC
615	615	AP	DISCHARGE TI
1616	1616	AP	INSTALL MIRR
616	616	AP	MIRROR & LAS
617	617	AP	LIDAR FUNCTI
1619	1619	AP	INSTALL DETE
619	619	AP	VISIBLE DETE(
1623	1623	AP	INSTALL RADI(
623	623	AP	MICROWAVE RA
1634	1634	AP	INSTALL RADA
634	634	AP	RADAR TEST &
1639	1639	AP	INSTALL TRAC
639	639	AP	DUAL STAR TR
1640	1640	AP	INST TRACKEI
640	640	AP	ASSY OF STAR
1657	1657	AP	INSTALL DETE
657	657	AP	CHAR. OF TV D
1659	1659	AP	INSTALL ZOOM
659	659	AP	ZOOM LENS CH/
673	673	AP	DIRECT. SFERI(
1700	1700	AP	INSTALL RADIC

31 7 46

'ECTOR	3	3	1
R – SPACE EFFECTS	120	4	73
ECTOR	4	4	1
CHAR – COOLING	168	3	16
TO MULTIP TUBE	3 5	3 5	1
TERISTICS – RADIOM	168	3	8
RINGS	4	4	1
BALS BEARINGS, ZOOM	168	25	10
ICAL EQUIPMENT	4	4	3
AL ELEMENTS	720	3	2
TO MULTP TUBE	3	3	1
TION (SEARCHLIGHT)	4	3	6
RORS	4	4	4
GHT – MIRRORS (SEARCHLIGHT)	2	2	2
HARGE TUBE	3 5	3 5	1
BE SPEC (SEARCHLIGHT)	6	3	5
OR & LASER	4	4	4
ER MOUNT & ALIGN	168	5	2
ON EVAL	3	25	10
CTOR	4	4	8
CTORS – CHAR & COOLING	24	5	10
METER	4	2.5	8
DIOM PERFORM	168	5	20
R	4	4	18
PROCEDURES	168	[illegible]	30
KER PLATFORM	3 5	3 5	2
ACKER	96	5	5
R	3[illegible]	3.5	2
TRACKER EVA	120	.5	3
CTOR	3.5	3.5	1
ETECTORS	72	5	3
LENS	3	3	1
ARACTERISTICS	168	5	3
S RECEIVER	24	1	20
METER	4	4	8





[redacted]

[redacted]

[redacted]

35

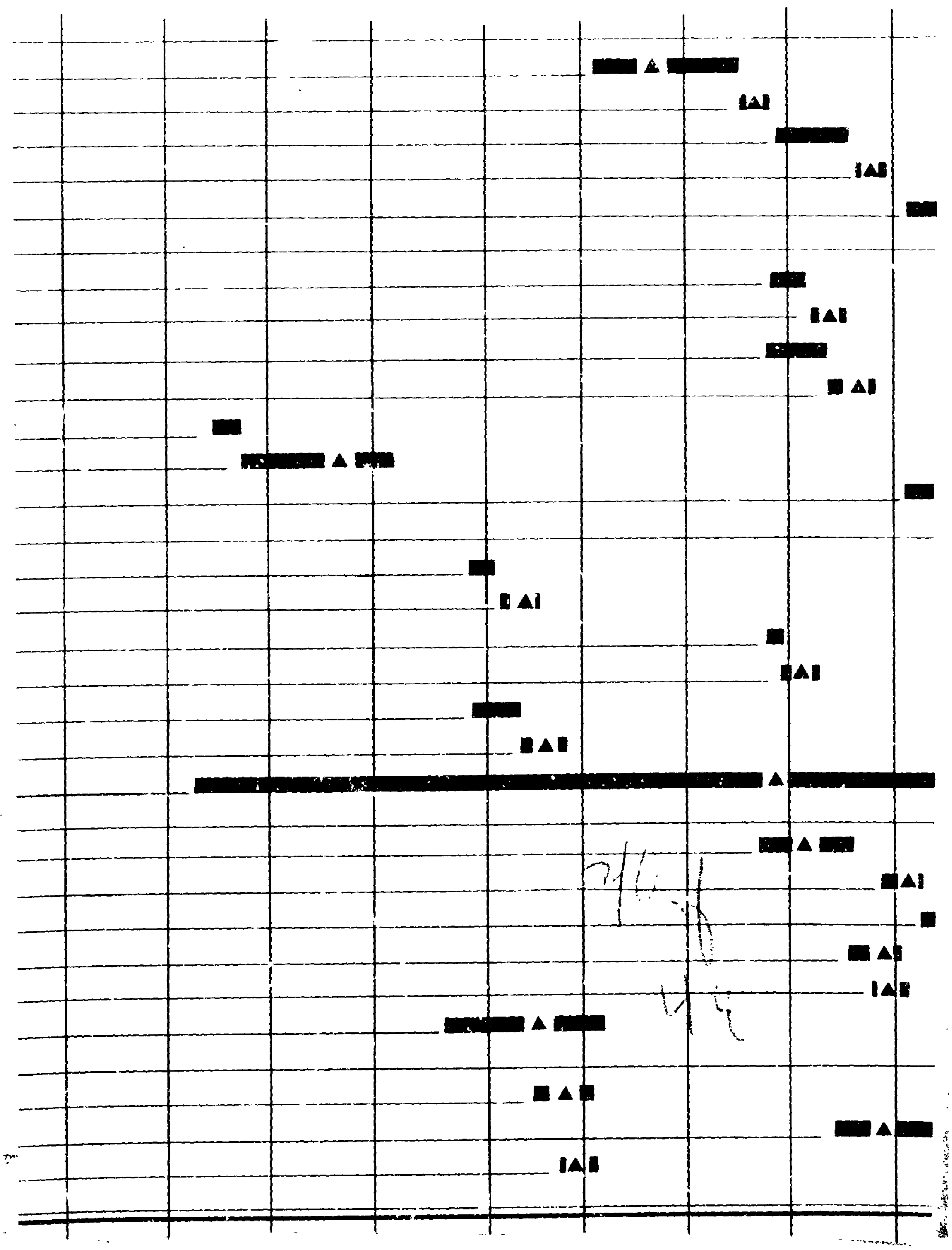
[redacted]

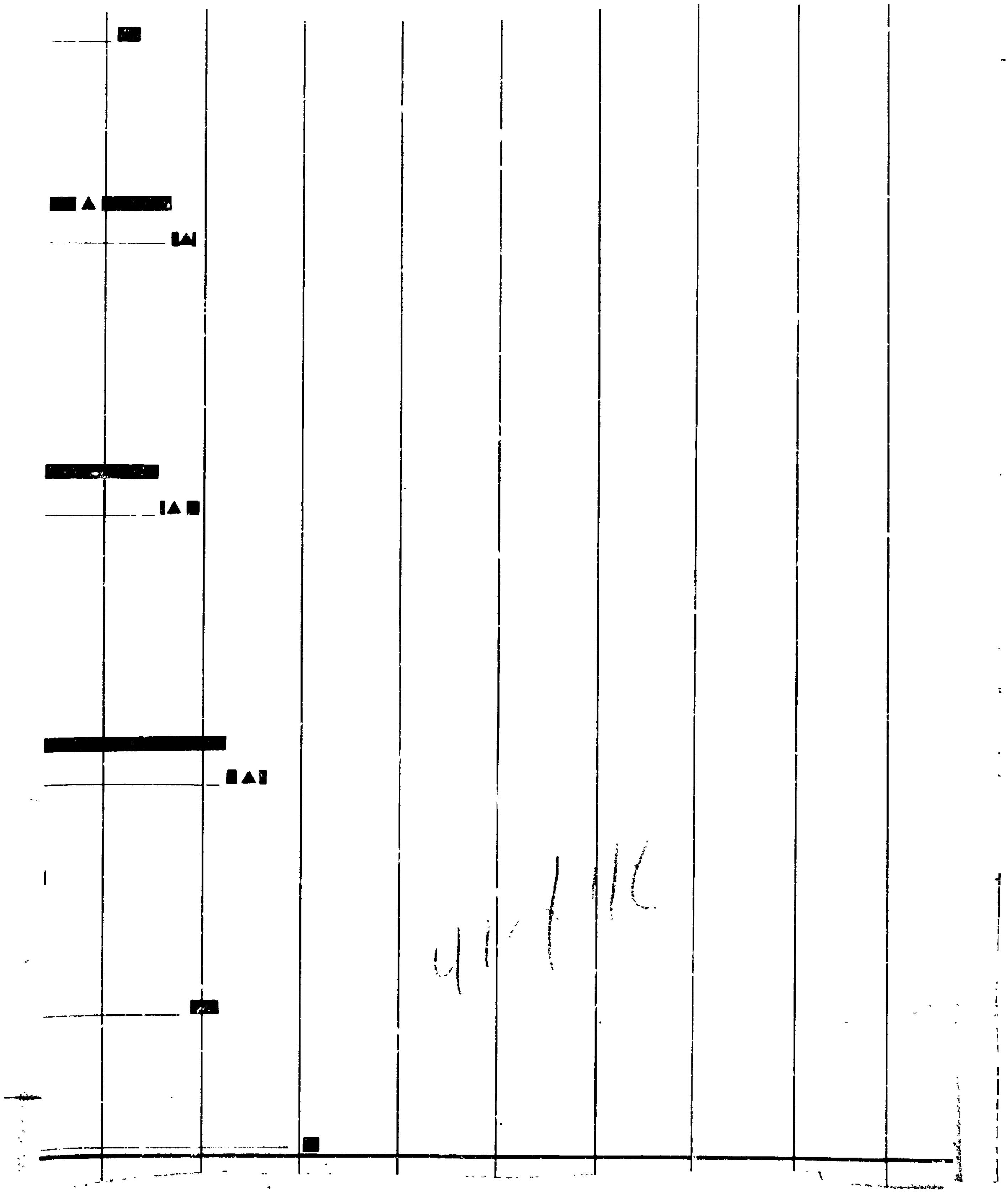
36-5 48

700	700	AP	WIDE
1703	1703	AP	INST
703	703	AP	DUAL
1704	1704	AP	INSTA
704	704	AP	IR SF
1705	1705	AP	INSTA
705	705	AP	DUAL
1710	1710	AP	INSTA
710	710	AP	POLA
1711	1711	AP	INSTA
711	711	AP	UV SI
1713	1713	AP	INSTA
713	713	AP	DUAL
1716	1716	AP	INSTA
716	716	AP	IR IN
1718	1718	AP	INST.
718	718	AP	TV S
1719	1719	AP	INST
719	719	AP	IR CA
1721	1721	AP	INST.
721	721	AP	DUAL
1723	1723	AP	INST
723	723	AP	DIRE
753	752	AP	DUAL
754	754	AP	IR SF
758	758	AP	VISIE
760	760	AP	POLA
761	761	AP	UV SF
763	763	AP	DUAL
766	766	AP	IR IN
768	768	AP	TV S
769	769	AP	IR C
771	771	AP	DUAL
773	773	AP	DIRE

BAND VIS RADIOMETER	4	4
RADIOMETER	4	4
CHANNEL VISIBLE RADIOM	4	4
ALL IR SPECTROMETER	4	4
'ECTROMETER	4	4
ALL UV RADIOMETER	4	4
CHAN UV RADIOMETER	4	4
ALL POLARIMETER	4	4
RIMETER (VISIBLE)	13	[illegible]
ALL SPECTROMETER	4	4
PECTROMETER	13	4
ALL STAR TRACKER	4	4
STAR TRACKER	22	7
ALL EQUIPMENT	4	4
TERFEROMETER & IR SPECTROMETER	13	4
ALL TV	4	4
YSTEM	14	6
ALL CAMERA	4	4
MERA	13	7
ALL TV	4	4
CHANNEL TV	14	10
RECVR & ANTENNA	4	4
CT SFERICS RECEIVER	9	3
CHANNEL VISIBLE RADIOM	6	2
'ECTROMETER	1.5	1.5
LE RADIOMETER (WIDE BAND)	1.5	1
ARIMETER (VISIBLE)	1.5	.75
PECTROMETER	1.5	1
STAR TRACKER	24	[illegible]
TERFEROMETER IR SPECTROMETER	1.5	1
YSTEM	1.5	1
AMERA	72	3
CHANNEL TV	1.5	1
CTIONAL SFERICS RECEIVER	1.5	1

10
8
10
4
10
8
10
4
10
4
10
4
20
4
10
4
10
2
10
4
10
18
20
20
30
20
20
20
30
30
30
10
20
20





FUNDAMENTAL RESEARCH	2140	IB 15	DATA BANK	
	2141	IB 16	DATA BANK	
	2142	IB 17	DATA BANK	F
	2143	IB 18	DATA BANK	
	2144	IB 19	DATA BANK	
	2145	IB 20	DATA BANK	C
	2146	I	DATA BANK	
	2147	IA 8	DATA BANK	L
	2148	IA 7	DATA BANK	S
	2149	IA 5	DATA BANK	E
	2150	IA 6	DATA BANK	
	2151	IIC 10	DATA BANK	S
	2152	IA 12	DATA BANK	S
	2153	IA 2	DATA BANK	A
	2154	IA 4	DATA BANK	I
	2155	IC 12	DATA BANK	P
	2156	IC 11	DATA BANK	F
	2157	IC 7	DATA BANK	F
	2158	IC 8	DATA BANK	M
	2159	IC 9	DATA BANK	P
	2160	IIA 4	DATA BANK	A
	2161	IIIB 15	DATA BANK	O

43 of 45

FEEDING SURVIVAL AND REPRODUCTION OF THE DAPHNIA PULEX IN SPACE ENVIR	24	5	30
DISCRIMINATION AND COMMUNICATION OF ANIMALS	24	5	30
PHOTOSYNTHETIC ACTION SPECTRA OF ALGAE CULTURES	24	1	5
OFFSPRING CONCEIVED DEVELOPED AND BORN IN THE WEIGHTLESS STATE	24	2	109
ORIGIN OF BIOCHEMICAL COMPOUNDS	24	5	30
CEREBRAL NEURONAL AND GLIAL CHEMISTRY	24	3 5	30
COSMIC DUST MEASUREMENTS	8760	4	2
LARGE APERATURE TELESCOPE EVALUATION	24	4	6
PACE RADIATION TELESCOPE EVALUATION	24	5	365
EXTRATERRESTRIAL EM RADIATION SURVEY	24	4	365
XTRATERRESTRIAL EM RADIATION SURVEY	24	3	365
PECTRAL ANALYSIS OF STAR SOURCES FOR SPACE NAVIGATION	72	4	121
OLAR CORONA AND SOLAR FLARE OBSERVATION	720	4	12
ARTIFICIAL METEORS OBSERVATION	24	1	1
ONIZED CLOUDS IN SPACE	1440	75	6
PARTICLE PHYSICS USING NUCLEAR EMULSIONS	168	1	52
PARTICLE PHYSICS USING SPARK CHAMBER	240	1	10
PLANETARY AND SATELLITE SURFACE PROPERTIES	24	3	1
EASUREMENT OF NON-GRAVITATIONAL FORCES	72	4	10
ARTICLE INJECTION STUDY	24	2	30
URORAL SURVEY	720	1 5	12
BTAINING LOCALIZED ULTRAHIGH VACUUM	24	2	32

4-6-65

[redacted] ▲ [redacted]
[redacted] ▲ [redacted]
[redacted] ▲ [redacted]
[redacted] ▲ [redacted]
[redacted] ▲ [redacted]
[redacted] ▲ [redacted]
[redacted]
[redacted] ▲ [redacted]
[redacted] ▲ [redacted]
[redacted]
[redacted] ▲ [redacted]
[redacted] ▲ [redacted]
[redacted] ▲ [redacted]
[redacted] ▲ [redacted]
[redacted] ▲ [redacted]
[redacted]
[redacted] ▲ [redacted]
[redacted] ▲ [redacted]
[redacted] ▲ [redacted]
[redacted] ▲ [redacted]

[illegible]

[redacted]

[redacted]

[redacted]

46 + 4[illegible]

[illegible]

44618