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EXTENDED APOLLO SYSTEMS UTILIZATION STUDY

Final Report
Volume 23
Condensed Summary
(U)

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FOREWORD

This volume constitutes a portion of the Apollo X Study final report (SID 64-1860) prepared as part of the Extended Apollo Systems Utilization Study conducted by the Space and Information Systems Division of North American Aviation, Inc., for the National Aeronautics and Space Administration's Manned Spacecraft Center under Contract NAS9-3140, dated 6 July 1964. S&ID acknowledges the outstanding technical contributions made to the study by a number of companies; these organizations are identified below along with the title of the report for which they are responsible.

The final report has been prepared in a series of 23 volumes as listed below:

1. Summary
2. Mission and Performance Analysis
3. Experimental Programs
4. Configurations, Structures, and Weights
5. Mission Plans and Functions
6. Environmental Control System (AiResearch)
7. Fuel Cells (Pratt & Whitney)
8. Alternate Power Source (General Electric)
9. Cryogenic Storage System (Beech Aircraft)
10. Service Module SPS Engine (Aerojet)
11. Command Module RCS Engine (Rocketdyne)
12. Service Module RCS Engine (Marquardt)
13. RCS Propellant Tanks (Bell)
14. Guidance and Navigation (A-C Sparkplug)
15. Alternate Guidance System (Autonetics)

16. Guidance Computer (Raytheon)
17. Stabilization and Control System (Honeywell)
18. Communications and Data System (Collins Radio)
19. Earth Landing System (Northrop-Ventura)
20. Subsystems Supplement
21. Reliability and GSE
22. Development Planning
23. Condensed Summary

This document, Volume 23, Condensed Summary, is presented in a format and within page limitations specified by NASA. It is intended to convey a broad, cursory view of the Apollo X part of the Extended Apollo Systems Utilization Study. The reader is urged to refer to other volumes of this report for more detailed information.

INTRODUCTION

The NASA Manned Spacecraft Center (MSC) has for the past few years examined the application of the Apollo spacecraft to missions alternate to the basic lunar landing mission for which it is now designed. The overall objective of these studies is an assessment of the advantages and disadvantages associated with the application of developed hardware to these other potential missions.

NASA studies of near-term applications of interest, which represent possible initial extensions to current Apollo capabilities, include use of the Apollo spacecraft as: (1) a space station logistics resupply vehicle (carrying up to six men), (2) an earth orbital space station or experimental laboratory, and (3) a lunar mapping and survey vehicle. This report presents results of the most recently concluded studies of the Extended Mission Apollo, in which alternative applications to a 45-day earth orbital laboratory role or to extended lunar orbital missions have been examined.

The initial Extended Mission Apollo study, initiated in August 1963 under contract to the MSC, examined the suitability of the Apollo as an orbital biomedical and behavioral experimental laboratory. These experiments were to provide a basis from which man's suitability for protracted space missions could be determined. Three basic configuration concepts (Figure 1) were investigated at the outset of the study. Concept I utilizes only the Apollo command and service modules (CSM), with experimental in-orbit work space made availabe in the command module by reducing crew size to two men. The Apollo CSM subsystems were modified to sustain orbital operations for periods of up to 120 days without resupply. Concept II consisted of the Apollo CSM plus a 5600-cubic-foot laboratory module built within the geometric limits of the LEM adapter. In this concept, the CSM subsystems support the laboratory module functions for the 120-day resupply period, the laboratory, consequently, being dependent on the CSM subsystems. Concept III is similar to Concept II with respect to the addition of the separate laboratory module within the LEM adapter section; however, the Concept III laboratory was designed to carry its own subsystems and is, therefore considered to be independent of the CSM. The subsystems in the

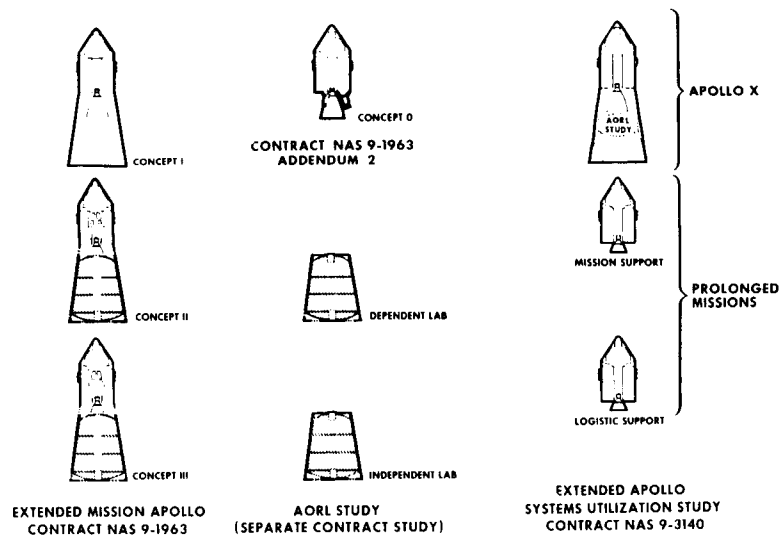

Figure 1. System Evolution

independent laboratory module were designed for one-year continuous operation, with resupply of expendables by the Apollo CSM as required. Included in the original Extended Mission Apollo study was the establishment of detailed development plans, including costs, schedules, and manufacturing and facilities plans. These development plans were based on an integrated, but noninterference,

relationship with the Apollo program, and on maximum utilization of Apollo technology, facilities, etc. The laboratory module, for example, used a large percentage of Apollo/Saturn interstage tooling.

Results of the initial Extended Mission Apollo studies revealed several additional factors that warranted further investigation. The required 120-day resupply cycle dictated the use of advanced subsystem concepts in several areas. Also, although the feasibility of extending the life of the current Apollo subsystems had been established in the study, specific techniques for accomplishing this life extension had yet to be determined.

For these reasons, further studies were initiated as an addendum to the Extended Mission Apollo contract. The purpose of these additional studies was to define the design characteristics and the maximum earth orbital mission duration of the Apollo CSM, assuming restriction to use of existing Apollo subsystem concepts. This CSM configuration was identified as Concept 0. Included in the study was examination of each subsystem to determine the life extensions possible through the addition of spares and redundancies. The study concluded that the Concept 0 orbital duration capability was approximately ninety days (based upon Saturn IB payload limits).

After review of these findings, NASA initiated the current Extended Apollo Systems Utilization Study. The first part of this study, reported herein, was to define in depth the design and operational characteristics of a vehicle based upon the identical subsystems approach employed in Concept 0, but arbitrarily limited to a 45-day maximum mission duration. This vehicle, identified as Apollo X, appears to represent the logical next step in manned spacecraft duration capability beyond the current Apollo and Gemini programs. In the second part of this study program, the characteristics of the CSM configurations associated with dependent and independent laboratory modules (as in Concepts II and III) are being investigated relative to earth orbital missions of greatly extended durations. Under these "Prolonged Mission" studies, the Concept II CSM is identified as a "mission support" vehicle, since it provides the subsystems functions for the laboratory as well as resupplying crew members and expendables. The Concept III CSM is identified as a "logistics support" vehicle, since it resupplies only expendables and crewmen, the CSM subsystems remaining in a quiescent state after docking to the laboratory module. The laboratory modules are being investigated separately (i. e., by another contractor) under the current NASA study program. Accordingly, definition of the characteristics of the laboratory modules is not included as part of this report.

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OBJECTIVES

The Apollo X study was initially focused toward consideration of earth orbital experimental missions of up to 45-day durations; the spacecraft and subsystems requirements were to be developed through the determination of the experimental mission requirements. Secondary studies were aimed at determining the modifications required to the 45-day earth orbital CSM design when applied to a lunar survey mission (including up to 28 days in lunar polar orbit). Several weeks after study initiation, however, NASA directed that equal attention be given to the lunar survey mission, and requested that primary emphasis be placed on the definition of a standard CSM suitable for both the lunar and the earth orbital applications.

Therefore, the primary objective of the Apollo X study has been to define a "standard" spacecraft design capable of alternately performing extended duration lunar missions or earth orbital missions of NASA near-term interest. Included in this primary objective were studies to determine specific modifications required for each subsystem to accomplish the extended missions. Subsystem qualification test programs, which would substantiate the analytically derived extended life subsystems, were also defined. In the experimental area, emphasis was placed upon the definition and integration of experimental packages (for earth orbital missions), based upon experimental lists provided by NASA at the outset of the study. As an aid to NASA evaluation of the desirability of, or requirement for, the laboratory module, studies were also performed defining development factors based on CSM changes attendant with and without the laboratory module. All development factors investigations were based on an integrated, but noninterference, relationship with the current Apollo program.

METHOD OF APPROACH AND PRINCIPAL ASSUMPTIONS

The overall study approach was based upon the derivation of a standard multimission CSM that could be applied to a number of vehicle configuration arrangements, as indicated in Figure 2. In the "Basic Configuration" (Figure 2), experimental work space is made available in the command module by eliminating the third crew member and couch and providing for in-orbit stowage of the center couch under the pilot's (left-hand) seat. This configuration is adaptable only to earth orbital experimental missions, since lunar missions require that the service module be completely filled with propellant, fuel cells, cryogenic tankage, etc., leaving no remaining volume available for mission-oriented equipment. However, the basic configuration has the definite advantage of being able to provide an experimental laboratory for early flights (such as biomedical and human factors experiments), without schedule dependency upon a separate laboratory module. Additionally, data resulting from these early flights would build a high-confidence base for performing subsequent missions of high complexity with a laboratory or lunar survey mission module.

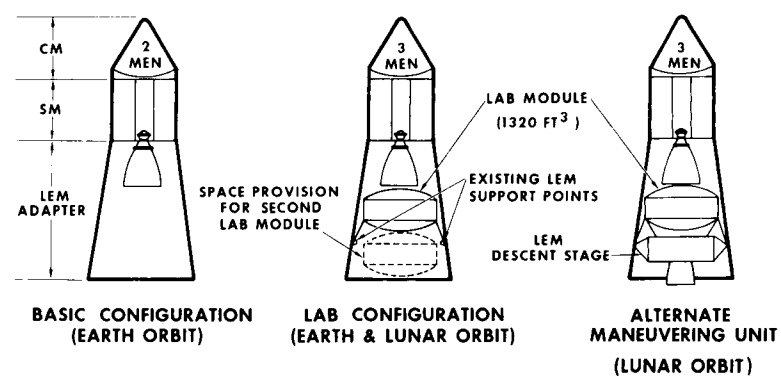

Figure 2. Apollo X Concepts

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The Apollo X concept is currently included by NASA under the Apollo Extension Systems (AES) program, which broadly defines a number of alternate uses of the Apollo spacecraft. Included under this program is the use of the lunar excursion module (LEM) ascent stage as a laboratory for the Apollo X. During the Apollo X study, however, requirements for the CSM were obtained assuming development of a completely new laboratory module design, as indicated in Figure 2. This approach is more conservative with respect to the severity of CSM requirements since the laboratory module assumed has a much larger volume than the LEM. The separate laboratory module is being investigated under separate contract; therefore, laboratory module definition was beyond the scope of the Apollo X study. A limited amount of effort was performed by S&ID, however, to determine CSM requirements resulting from the addition of this separate laboratory module

The separate laboratory module (with a volume of approximately 1200 to 1500 cubic feet) is sized by the provision of space inside the LEM adapter for a second module of identical geometry. This configuration can be applied to any of the earth orbital and lunar missions of current interest, with mission-peculiar payloads installed within the laboratory module. The configuration is extremely versatile in that the experimental volume availability can be controlled by the addition of either one or two laboratory modules. In addition, a single module can be mounted on the LEM descent stage, thereby permitting additional payload for lunar missions (through increased delta V capability), orbital plane changes, or landing the module on the lunar surface for lunar base support.

All technical studies started with the technical base of the Apollo Block II configuration. Since past studies revealed that subsystems characteristics materially influenced configuration design, heavy emphasis was placed upon subsystems definition as indicated in Figure 3. In this regard, not only primary subsystem components were examined in detail, but secondary components were also fully analyzed. Where it was found that the addition of spare or redundant Apollo subsystem components might not suffice for the extended life application, product improvement areas were identified and tentative solutions established.

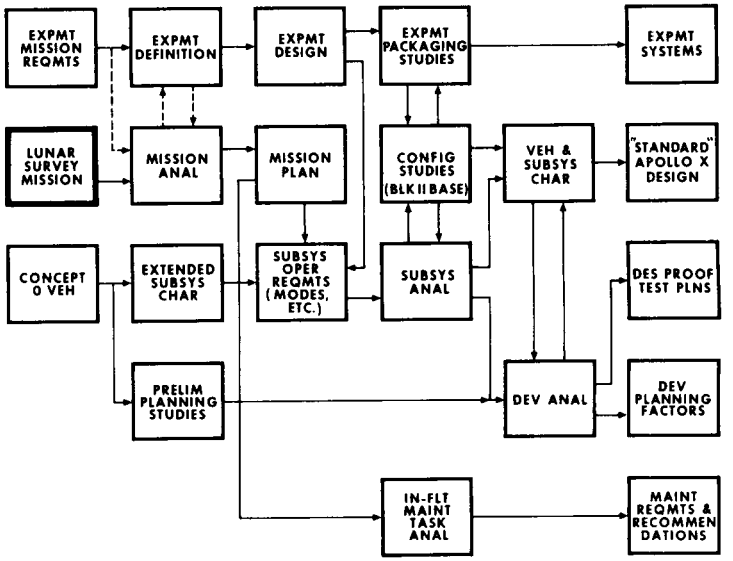

Figure 3. Apollo X Study Approach

Previous studies had identified in-flight maintenance as a potential problem in view of the number of spares and redundant components employed for subsystem life extension. Correspondingly, inflight maintenance was examined with regard to possible ways of implementing these spares and redundancies as well as determining the demands on crew time. These requirements were integrated into crew experimental and station-keeping activities and were accounted for in the crew tasks scheduling. In the experiment design and packaging analyses, the biomedical and behavioral measurements were examined in detail by the application of data generated in earlier Extended Mission Apollo studies.

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BASIC DATA GENERATED AND SIGNIFICANT RESULTS

This section describes the significant studies performed to determine the characteristics of a standard Apollo X design for performing (or supporting) all NASA near-term lunar and earth orbital missions. For convenience, the discussion is divided into four major areas: Mission and Systems Analysis, Configuration and Performance Analysis, Subsystems Analysis, and Operational Implementation. The Mission and Systems analysis portion describes the development of the Apollo X operational requirements. These requirements were translated into design requirements upon which the Subsystems Analysis and Configuration and Performance Analysis studies are based. The resulting design definitions were then subjected to development planning analyses which are presented in the Operational Implementation section.

MISSION AND SYSTEMS ANALYSIS. Mission requirements for the standard Apollo X design result from consideration of both earth and lunar objectives. The lunar objective is operational in nature and involves complete mapping of the lunar surface. The earth orbital objective considers all experiments that would result in the general advancement of man's knowledge and also includes experiments that would provide useful data for increasing the confidence of achieving future extended mission operational objectives.

A review of the design requirements imposed by all missions upon the vehicle and its subsystems indicates that, with one exception, the most critical demands are associated with the lunar mapping mission. The one exception is the communication and data system, the requirements for which are determined by the data flow attendant with an earth orbital biomedical and behavioral mission.

The lunar mapping mission requires complete photographic coverage of the moon, including duplicate coverage of every surface point. Because of the cryogenic storage volume limitations of the service module, this mission cannot be accomplished without a separate laboratory module. Included in this laboratory module are cartographic and spectral-zonal cameras, with TV for monitoring and control. The camera package characteristics are based upon a mapping system defined by NASA studies. In order to adequately meet the mapping requirements, 28 days in lunar orbit are required. This is based upon the rotation of the moon's surface beneath the orbit plane on the lighted side of the moon; since the moon's rotational period about the earth is 28 days, the same amount of time is required for all surface points to pass beneath the orbit plane under favorable lighting conditions. Additional requirements include an orbit altitude of 80 nautical miles, orbit velocity knowledge within ±4 feet per second, and an altitude knowledge within ±1500 feet. During the mapping phases, attitude of the vehicle must be within ±0.5 degrees, with an allowable attitude rate $\leq$ 0.02 degrees per second for a total of 82.5 hours. In order to meet the requirement for duplicate coverage of every lunar surface point, it is necessary that the mapping profile be conducted as shown in Figure 4. Coverage characteristics are such that mapping is conducted every third orbit. A complete half-orbit mapping run occurs every sixth orbit, with a small patch (between latitudes 45 degrees north and 45 degrees south) required between these half orbit runs as shown by the fourth orbit in Figure 4. Excessive film footage is accumulated over both polar regions, but is required due to poor lighting conditions in these areas.

The earth orbital experimental missions are based upon a logical evolution of experimental complexity and usefulness as shown in Table 1. The missions shown were developed only to determine

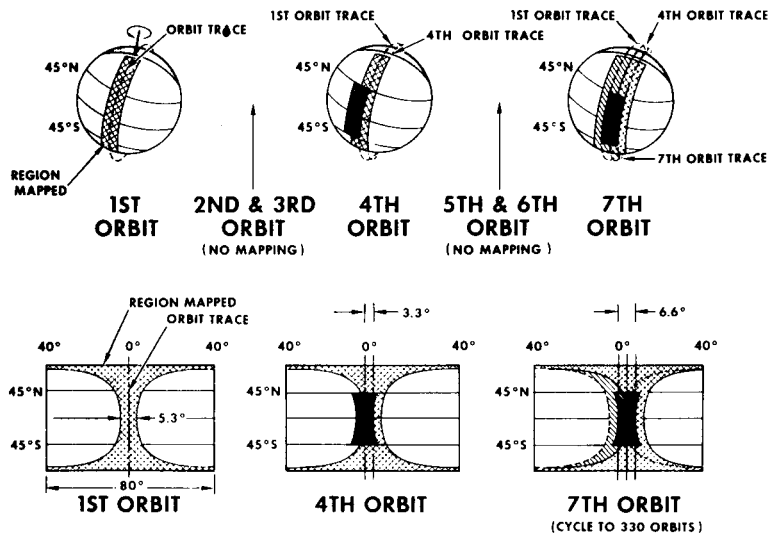

Figure 4. Lunar Mapping Operations

CSM vehicle and subsystem demands and, as such, are only representative of those that might be employed by NASA in the Apollo X vehicle. The primary objective of the flights performed under Mission Plan 1 is to determine the ability of man to survive and perform in extended space missions. Mission Plan 3 would be performed primarily as a qualification of the lunar mapping system in earth orbit. The experiments for each of the configurations are selected on the bases of equipment commonality and of demands on the crew, the vehicle, and its subsystems. The weights shown are not spacecraft limited, but are the result of arbitrary mission and experiment groupings. These demands are well within the existing capability of the standard Apollo X design in all respects except for the power and attitude-hold requirements under Mission Plan 2, as shown in Table 2. The deficiency in the power system area can be eliminated through removal of one experiment dealing with friction and lubrication properties. Additionally, the relaxed lunar reliability and abort criteria for earth-orbit missions will permit adequate attitude-hold time for performance of the astronomical earth-orbit mission.

Table 1. Selected Earth Orbit Experimental Missions

	MISSION PLAN 1		MISSION PLAN 2		MISSION PLAN 3
DURATION	30-45 DAYS		30-45 DAYS		34-45 DAYS
INCLINATION	28.5°		28.5°		90°
BOOSTER	S-IB		S-IB		S-V
CONFIG	A	B	A	B	–
	CSM ONLY	LAB MODULE	LAB MODULE	LAB MODULE	LAB MODULE
CREW SIZE	2	3	3	3	2 OR 3
PRIMARY EXPER PURPOSES	MAN'S WELL-BEING & EFFECTIVENESS	MAN'S WELL-BEING & EFFECTIVENESS	SCIENCE & ENGRG	ASTRONOMICAL	LUNAR MAPPING DEV
MAJOR EQUIP CONFIG	• BAHF • EXTERNAL CARRIER	• BAHF • EXTERNAL CARRIER • CENTRIFUGE	• DRAG BOOM • SENSOR TOWER • ADV G&N SYS	• TELESCOPE PLATFORM • AIRLOCK • METEOROID LAUNCHER	• MAPPING CAMERAS • METEOROID COLLECTOR • ION ENG TEST MOUNT • EXTERNAL SENSORS
MAJOR SYS DEMANDS	• CREW TIME • VOLUME	• CREW TIME • EQUIP WT	• POWER	• STABILIZATION • EXTRA-VEH ACTIVITY • EQUIP WT	• STABILIZATION • EQUIP. WT

Table 2. Experimental Package Summary

	MISSION PLAN 1		MISSION PLAN 2		MISSION PLAN 3
	2-MAN BAHF	3-MAN BAHF	SCIENTIFIC	ASTRO-NOMICAL	MAPPING
TOTAL CREW TIME (HR)	437/813	700/1247	253/1247	205/1247	384/1247
WEIGHT (LB)	445	1068	547	1501	2258
VOLUME (FT^3)	27	54	56	52	55
POWER (KW HR)	25/216	32/216	565/216 OR 49*/216	16/216	31/216
ATTITUDE HOLD REQMTS (HR)	0	0	70/82.5	146/82.5**	82.5/82.5

*BY ELIMINATING ONE EXPERIMENT (FRICTION & LUBRICATION STUDIES)
**EARTH ORBIT RELAXED ABORT CRITERIA WILL INCREASE AVAILABLE HR

Biomedical and behavioral experiments were investigated to a much greater depth than other experiments, since they are based upon previous studies of a similar nature sponsored by NASA. These experiments have been defined sufficiently by this study to permit the establishment of equipment specifications as a next study phase. For each biomedical and behavioral measure, individual procedure cards were prepared which illustrate exact procedures required for the subject, observer, and machine, including the time involved. A total of 105 biomedical measures are required in order to assure a confidence value of 100 percent with regard to measuring man's physical well-being. After elimination of measures which were regarded as not feasible for spacecraft application, an adjusted confidence value of 83 percent results for the remaining measures. For the two- and three-man vehicles, confidence values of 70 and 83 percent, respectively, can be achieved with the measures shown in Table 3. Confidence values of approximately 80 and 83 percent can be achieved with the selected behavioral measures for the respective two- and three-man configurations.

The primary purpose of the operations experiments is to evaluate the capabilities of man to perform specific space functions, including force producing capabilities, evaluation of controls and instrument displays, rendezvous and docking techniques, and crew and cargo transfer techniques. A number of the human force-producing characteristics experiments can be used to evaluate man's ability to perform basic manual operations in space. A preliminary concept of an ergonomic force testing unit was developed, including load shaft adapters, that can measure these forces and motions.

After eliminating experiments that might be performed more profitably on the ground or in unmanned spacecraft, 241 recommended experiments in the natural sciences and engineering area were derived. The subcategories of selected experiments are based on general scientific disciplines, specific NASA experiment requirements, and the capabilities of available consultants in most fields of space science and engineering. As a part of the experimental integration studies, a variable auxiliary experimental panel was defined which can be integrated into the CM main control and display panels. The auxiliary panel contains a surface area of 455.5 square inches. A number of auxiliary panel arrangements were also established, including a telescope control and display panel and an integrated real-task simulator panel.

Table 3. Integrated Biomedical Measures

MAJOR BODY SYS	CONFIDENCE VALUE AS % OF TOT MAN	NO. OF MEAS DEFINED	ADJ* CONFI-DENCE VALUE	2-MAN		3-MAN	
				NO. INTE-GRATED	VALUE	NO. INTE-GRATED	VALUE
CARDIOVASCULAR	23	17	10	6	6	11	10
URINARY & BODY FLUID	14	13	13	10	12	12	13
RESPIRATORY	16	11	16	9	14	11	16
NERVOUS	9	13	9	13	9	13	9
MUSCULOSKELETAL & ARTICULATION	14	10	14	9	12	10	14
ENDOCRINE & METABOLISM	6	12	5	8	5	9	5
HEMATOPOIETIC & BLOOD	13	15	11	8	7	13	11
DIGESTIVE	4	10	4	9	4	9	4
INTEGUMENT	1	4	1	4	1	4	1
TOTAL	100	105	83	76	70	92	83

*AFTER ELIMINATION OF NONFEASIBLE MEASURES

Previous studies had indicated that the operating life of Apollo subsystems could be extended by addition of a number of spares and redundancies. Employment of these spares and

redundancies could either be automatic, semi-automatic (manually switched), or manual in nature; the specific mode selected could severely influence experimental capability by imposing severe demands upon crew time. A review of all additional subsystems components required for the standard Apollo X design indicates that manual installation is required in only two instances, as shown in Table 4. Of these two cases, one can be regarded as a station-keeping function, since it involves periodic replacement of the lithium hydroxide canisters in the environmental control system for CO_2 removal. The remaining case is with the stabilization and control system where additional components must be added manually by the crew. All other subsystem components are implemented in the form of redundancies which would be employed either automatically or semi-automatically. As a result, scheduled inflight maintenance requires an insignificant amount of

Table 4. Life Extension Problem Scope, LSM Standard Vehicle

	FUNCTION	LOC	CREW ACC	REDESIGN REQD	REDUNDANT ELEMENTS	SPARES
POWER	SOURCE	SM	NO	PLUMBING & WIRING, H_2, O_2 TANKS, RADIATOR	2 FUEL CELLS	NONE
ENVIRON CONTROL	SOURCE ATMOS	SM	NO	N_2, O_2 TANKS	—	NONE
	DIST SYS	CM	YES	NONE	1 BLOWER 1 SUIT COMPRESSOR	NONE
	CO_2 REMOVAL	CM	YES	NONE	—	LiOH CANISTERS
SERVICE PROP.	PROP.	SM	NO	NONE	NONE	NONE
REACTION CONTROL	SYS	CM	NO	NONE	NONE	NONE
	SYS	SM	NO	PROP. & PRESS. SYS	NONE	NONE
STAB & CONTROL	ELECT.	CM	YES	ELECTR & ADD HORIZON SCANNER	NONE	GYRO PKG, & CONTROL ELECT. SCANNER PARTS
GUIDANCE & NAV	SYS	CM	YES	REMOVE INERTIAL COMP SUSPENSION	HTR SLIP RINGS FOR IMU	NONE
COMM	SYS	CM	YES	NONE	1 C-BAND X-PONDR	NONE
EARTH LANDING SYS	SYS	CM	NO	NONE	NONE	NONE
CREW SYS	FOOD STORAGE	CM	YES	RELOCATION	NONE	NONE
	WASTE MGMT	CM	YES	NONE	NONE	NONE
	HYGIENE	CM	YES	NONE	NONE	NONE

crew time (24 minutes per day) as shown in Table 5, which presents a breakdown of the total daily crew time demands for each mission. Significantly, each crew member has available an unscheduled contingency time of between four and eight hours per day. It is believed that scheduling of this available time would be unwise because of the possibility of unplanned equipment repairs.

Table 5. Crew Time Requirements, Daily Average

	EXPERIMENTAL MISSION				
	2-MAN BAHF	3-MAN BAHF	SCIENTIFIC	ASTRO-NOMICAL	MAPPING
SLEEP	15.0	22.5	22.5	22.5	22.5
PERSONAL (INCL FOOD)	9.0	13.5	13.5	13.5	13.5
SYS OPERATION	0.7	0.7	0.7	0.7	0.7
SAFETY PKG	3.9	5.8	5.8	5.8	5.8
SCHED IN-FLT MAINT	0.4	0.4	0.4	0.4	0.4
EST OF UNSCHED IN-FLT MAINT	0.1	0.1	0.1	0.1	0.1
BIOMEDICAL EXPERIMENTS	5.7	8.9	0	0	4.8
BEHAVIORAL & OPERATIONS EXPS	3.4	6.1	0	1.1	2.9
NAT'L SCI & ENGRG EXPMTS	1.1	1.3	5.9	3.7	1.2
TOTAL PLANNED TIME	39.3	59.3	48.9	47.8	51.9
UNSCHED CONTINGENCY TIME	8.7	12.7	23.1	24.2	20.1
TOTAL	48.0	72.0	72.0	72.0	72.0

CONFIGURATION AND PERFORMANCE ANALYSIS. Since the Apollo X potentially represents a very near-term NASA development, current operational constraints must be examined in depth to determine their influence on overall system characteristics. In this regard, range safety limitations presently employed by NASA at the Kennedy Spacecraft Center and current payload ratings of the Saturn 1B and Saturn V launch vehicles are considered as operational constraints for the Apollo X. Of major importance is the restriction to use of the standard Apollo/Saturn boost configuration, which

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limits expendables volume within the existing envelope defined by the command and service modules (CSM). However, tankage changes attendant with increased expendables requirements are permitted since changes of this nature cannot be considered significant from an overall system viewpoint. In a similar vein, changes to the Block II primary structure cannot be tolerated because of their negative influence on costs and schedules.

The three-man command module (CM) configuration is identical to the Block II Apollo except for elimination of certain crew equipment, spares, and scientific equipment associated with the LOR mission. Additionally, a data management control panel, common to all two- and three-man configurations, is installed in the food compartment area of the Block II lower equipment bay. Food storage for the extended missions would be provided by the separate laboratory module. For the two-man CM configuration, several changes of a minor nature are required. In order to provide volume for storage and performance of experiments, the elimination of the right hand crew couch is optimum, as shown in Figure 5. Additionally, disassembly and stowage of the center couch under the left hand crew couch position is facilitated by permitting crew members to stand in the space formerly occupied by the right hand couch during this operation. The elimination of the center couch rather than the right hand couch would not operationally permit such a procedure. The unsymmetrical attenuation loads resulting from elimination of the right hand crew couch require redesign of the seat attenuation system; however, redesign of this system will not require changes to the command module structure. Additionally, since the Block II seats are of a unitized construction, redesign of the crew couches is also required. The 60 Apollo LiOH canisters (for 90 man-days) will be stored

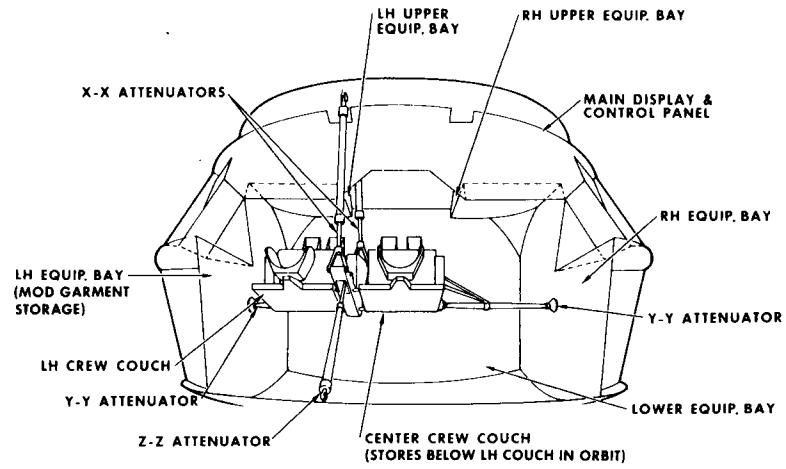

Figure 5. Apollo X Two-Man Crew Module Configuration

against the CM floor and lower equipment bay and in the floor area formerly used by the third crewman.

The two- and three-man Apollo X configurations have a common service module design. Two fuel cells are added in Sector 1 in order to provide extended operating life for both the lunar and earth orbital missions. Cryogenic and hydrogen tanks are added below the fuel cells in Sectors 1 and 4 and are sized by the 45-day earth orbital missions which impose the most critical expendables requirement of all missions. A cryogenic nitrogen tank is also added in the SM tunnel for provision of a mixed gas atmosphere. The existing Block II SPS tanks in Sectors 2, 3, 5, and 6 are required for the lunar mapping missions. For earth orbital missions where greatly reduced SPS propellant demands exist, smaller tanks will be required to eliminate center of gravity and potential fuel sloshing problems attendant with these reduced propellant quantities. The installation of these smaller tanks, however, will not result in any changes to the

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Block II feed system or plumbing. The reaction control system (RCS) tankage is sized by the lunar mapping mission which requires extended periods of lunar-oriented vehicle attitude. To meet the need for larger RCS propellant volumes, two sets of LEM tanks are installed in each of Sectors 2, 3, 5, and 6. These tanks are currently under development by NASA for the LEM vehicle.

The Saturn IB launch vehicle is used only in low inclination earth orbital applications and has the capability of delivering 29,600 pounds to a 200 n. mi., 28-1/2-degree inclined orbit. For polar orbits, however, use of the Saturn V launch vehicle appears necessary, since safety considerations presently limit the NASA launch azimuths at Cape Kennedy from between 72 to 105 degrees. This results in orbit inclinations of from 28-1/2 to 33 degrees maximum without plane changes during ascent. Current Air Force launch azimuth limits range from 50 to 105 degrees, with a special limit of 44 degrees on selected flights. With no launch azimuth restrictions, large payloads could be delivered to earth polar orbit as shown in Figure 6. However, within the existing NASA azimuth limit of 72 degrees, no polar orbit payload capability exists, since the entire payload must be made up of fuel for plane change during ascent. With the Air Force range limits (50-degree azimuth), however, payloads on the order of 40,000 pounds can be achieved. For an assumed laboratory module weight of 5,000 pounds, 20,000 pounds of service module propellant would be adequate to achieve earth polar orbit using a 53-degree launch azimuth as shown in Figure 7. Of primary significance is the sensitivity of orbital payload capability to launch azimuth. As indicated in Figure 7, by decreasing launch azimuth to 50 degrees, an additional 5,000 pounds of payload can be achieved, resulting in a total of 10,000 pounds in earth polar orbit (in addition to the CSM).

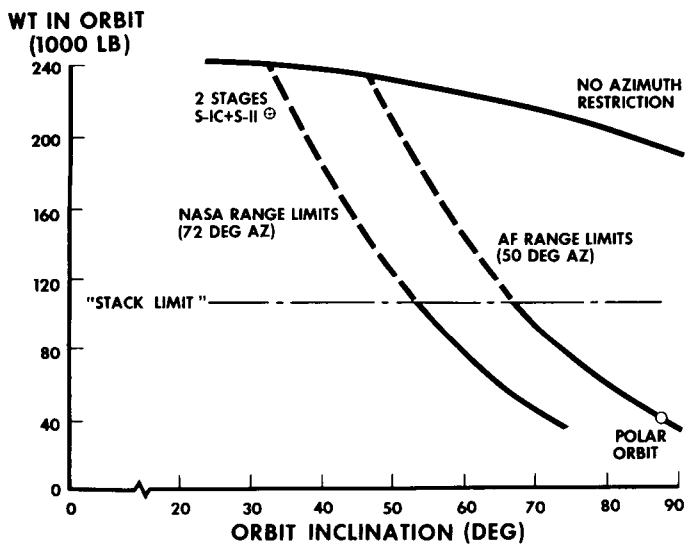

Figure 6. Saturn V Performance

For the lunar survey and mapping mission, a lunar polar orbit is required. The moon-earth phase-change relationship is such that the vehicle must possess plane change capability if the ability to abort at any given time is maintained. As a result, transearth delta V requirements vary according to the number of days after establishment of the initial lunar polar orbit as shown in Figure 8. The return-to-earth time can vary between 2-1/2 to 4-1/2 days, depending upon the trajectory considered. However, it is significant to note that a minimum delta V requirement of approximately 3,300 feet per second exists between the third and fourth day in lunar polar orbit, which is the same as that required for the Apollo LOR vehicle. At that particular point, no plane-change requirement exists for abort in the lunar mapping

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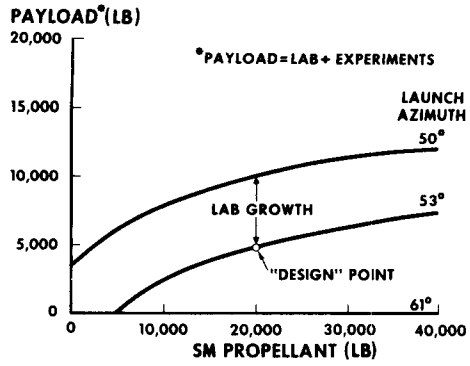

Figure 7. Earth Polar Orbit Capability

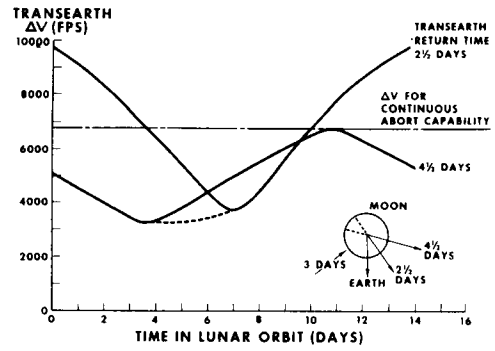

Figure 8. Abort Requirements for Lunar Polar Orbit

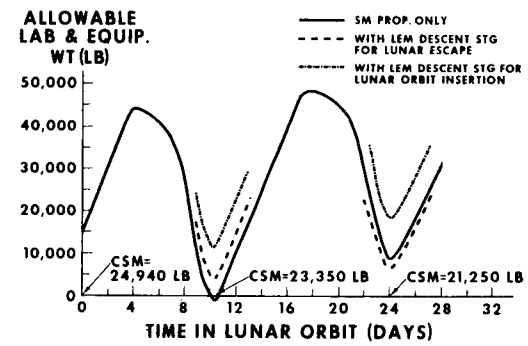

Figure 9. Lunar Polar Orbit Payload

mission. However, in order to maintain a continuous abort capability, the vehicle must possess sufficient propellant for a 6800 feet per second delta V. If this delta V capability is translated into allowable laboratory and equipment weight, this also varies as a function of time in lunar orbit as shown in Figure 9.

Assuming that only the service propulsion system is available for providing return-to-earth delta V, the ability to abort cannot be achieved between the ninth and eleventh days, assuming a laboratory weight of 5,000 pounds. With the addition of the LEM descent stage to the laboratory module (for additional delta V capability), two operational considerations are possible. The first would be to utilize the LEM descent stage for lunar orbit insertion. However, this scheme has insufficient propellant available in the LEM descent stage for the complete insertion phase. Therefore, a two-phase insertion must be made which requires 180-degree rotation of the configuration after burnout and separation of the LEM descent stage, with the remainder of the delta V requirement provided by the service module SPS. The second consideration would be to use the SPS for insertion into lunar orbit, maintain the LEM descent stage in an inert phase for the 28-day mapping period, then use the LEM descent stage for lunar escape.

The gross weight characteristics of all configurations are within the payload capabilities of the launch vehicles involved as shown in Table 6. Of interest is the 73,345-pound weight of the lunar

Table 6. Gross Weight Summary

	CONFIGURATION			
	BLOCK II (OCT 64)	3-MAN BAHF (AIRLOCK)	2-MAN BAHF	3-MAN LUNAR MAPPING
COMMAND MODULE	10,060	9,599	9,968	9,904
SERVICE MODULE	10,120	12,706	11,381	14,841
LABORATORY	29,500	3,694	—	4,611
ADAPTER	3,700	3,505	3,655	3,505
PROPELLANT	37,190	2,721	2,721	40,502
GROSS WT (LB)	90,570	32,225	27,725	73,345

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mapping configuration which does not require the maximum payload capability inherent in the Saturn V launch vehicle. It can be seen that this configuration is volume limited rather than weight limited, since the service propulsion system tanks are completely filled. The three-man biomedical and human factors configuration would have a laboratory weight considerably lower than that required for the lunar mapping mission because of the nature of the experimental activities involved. The total configuration weight of 32,225 pounds includes the LEM adapter which, when subtracted from the gross weight, results in a Saturn IB payload requirement of 28,720 pounds. This number is within the Saturn IB payload capability referred to earlier.

SUBSYSTEMS ANALYSIS. The Block II Apollo is designed for a lunar mission which provides an inherent capability for extended operation in earth orbit. This capability is a result of the abort criteria that was applied in the design of each Block II subsystem. For example, lunar mission abort is initiated when one additional system or component failure would eliminate the capability for safe return of the spacecraft and its crew. Therefore, each subsystem must function with a high level of confidence for the 40 hours required by the return-to-earth phase (after abort is initiated). In earth orbital missions complete subsystem failure can be tolerated since the abort (or return-to-earth) time is less than one hour. As a result, the Block II Apollo subsystems can function for a longer period in earth orbit (disregarding expendables) due to the component redundancies existing in each subsystem to meet the lunar abort criteria.

The existing Manned Spacecraft Control Center (MSCC) operational philosophy requires communication coverage before, during, and after thrusting, and also during orbit establishment (three to four orbits). Additionally, a system check must be made once every orbit. The present philosophy also dictates that only one critical mission phase can be handled at a time. Critical mission phases are defined as either an entire lunar flight or, for earth orbital missions, all mission phases except the orbital phase between the third to fourth orbit after orbit establishment and the third to fourth orbit prior to reentry. A critical mission phase is also defined as any time that system checks indicate a malfunction exists. Since the Apollo X missions will be accomplished in the same time period as Block II Apollo missions, the current operational philosophy would require either intermittent scheduling of Apollo and Apollo X flights or withholding Apollo X flights until the Apollo program is complete. An alternate would be to change the present philosophy so that more than one critical phase could be handled at a time. A second alternate would be to add additional equipment and personnel at the remote ground network sites and to add a new Mission Operations Control Room (MOCR) at MSCC; also, due to the increased data requirements, patch panel capability would have to be increased at Houston, including increased numbers of land lines and submarine cables. If simultaneous flights would not be acceptable, scheduling must be such that MSCC and its network have four to six weeks between flights for any reprogramming and checkout. The present capability of the ground network station is more than adequate to provide coverage for the Apollo X during all missions except those requiring earth polar orbits; however, the addition of one tracking ship in the Pacific will permit complete coverage for these missions.

The only changes to the Block II Apollo communications and data system are those required

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to facilitate tracking which is accomplished through the addition of a C-band transponder and antennas. The data system is more than adequate for all missions, including the biomedical and human factors mission which demands the highest data capacity. In this mission, the existing system is adequate for 57 days, using the biomedical and human factors operating profile. This capability is inherent in the Apollo system because of the current Block II philosophy which requires activation of the communication and data system throughout the entire LOR mission.

The Apollo X recovery system has a functional and operating profile identical to that of the Block II Apollo. The recovery weights of all Apollo X mission configurations are well within the Block II Apollo recovery system capability, which can accommodate in excess of 10,500 pounds hung weight. The major problem associated with the Apollo X recovery system is related to extended storage in a cold vacuum environment, during which out-gassing of substances such as waxes and seals occurs. To prevent out-gassing of these materials beyond acceptable quantities, seven pounds of a volatile substance will be added to the recovery bay to maintain slight pressurization throughout the mission. During the lunar mapping mission, recovery bay temperatures exceed those presently specified for the current Apollo Block II system. Continuous rotation (barbecuing) of the vehicle is required to bring temperatures within reasonable limits, as shown in Figure 10. However, during the mapping portions of the mission, temperature spikes occur which could reduce the recovery bay temperature to as low as -140 F. The addition of heaters, which require five watts of power, are indicated for the mapping portions of the mission and would bring the equilibrium temperature to approximately -85 F. Since the current Apollo Block II system is designed

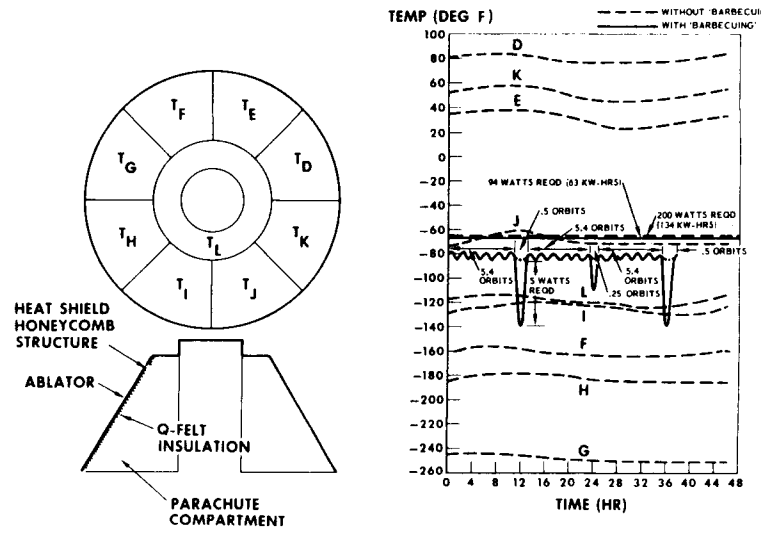

Figure 10. Parachute Compartment Thermal History for Lunar Polar Orbit

to -65 F, extended life testing will be performed to substantiate storage suitability in this lower temperature environment.

The environmental control system (ECS) is based on requirements for a two-gas atmosphere and support of the laboratory module for those missions where it is required. Additionally, due to possible experiments requiring extravehicular activity, a capability for ten CM repressurizations is provided. In the two-man configurations (without lab module), the only additions required are a nitrogen tank and plumbing system (with partial pressure controls) and additions of an extra suit compressor, debris trap, and catalytic burner (for trace contaminant control) in the suit loop. The addition of three Gemini LiOH canisters in the service module for CO_2 removal is a possible alternate for this configuration. However, adverse operational and technical problems more than

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offset any advantages of such an installation. As presently planned, the current Block II CO_2 removal method, with all canisters stored in the command module, will be employed. The addition of the laboratory module requires no changes to the Apollo X two-man ECS. The only additions required are contained in the laboratory module and consist of circulating fans and heat exchangers for laboratory thermal control and a blower for circulating the atmosphere between the CM and laboratory. The current Apollo Block II life support system is adequate for all Apollo X missions with additional storage required. Due to the unknowns related to crew experimental activities and prolonged weightlessness effects, a liquid supplement of 1,000 K-cals per man-day is added to the basic Apollo food requirement, resulting in a total of 4,000 K-cals per man-day for the Apollo X missions.

The most critical requirements for the guidance and control system are established by the lunar mapping mission. If the guidance and navigation (G&N) system is used for performing all phases of this mission, a large number of spares is required, including 36 spare modules for the Apollo guidance computer, one spare inertial measurement unit (IMU), and other spares related to the electronic coupling unit, displays and keyboard, and power and servo assembly. Of significance is the requirement for a spare IMU which would be extremely difficult to implement since this unit must be rigidly mounted and oriented to the CM structure. Additionally, this component is not accessible. If the G&N is used only for the earth-moon transphases of the mission, the Block II system is adequate without change. Another approach, which requires the addition of a horizon scanner for the provision of attitude control, is to use the stabilization and control system (SCS) for performing the mapping phases of the mission. SCS spares are also required in the control electronics assembly with adjustments required to the gyro assembly to account for variations associated with the horizon scanner addition. In certain earth orbital missions where the G&N is deleted, functions may have to be added to the SCS to provide for boost monitoring, which is currently provided by the Block II G&N. These additions are in the form of added components to the display assembly and a new entry display which would permit the crew to monitor boost and initiate abort. Without these additions, primary mode for these functions would be ground control.

A comparison of the two approaches may be found in Figure 11, which indicates a significant reduction in volume and weight if the SCS is modified for local vertical control during the mapping phases of the lunar mission. For low inclination earth orbits, where vehicle attitude orientation is not required, elimination of the G&N system would result in a weight reduction of some 370 pounds with a corresponding reduction in volume. The

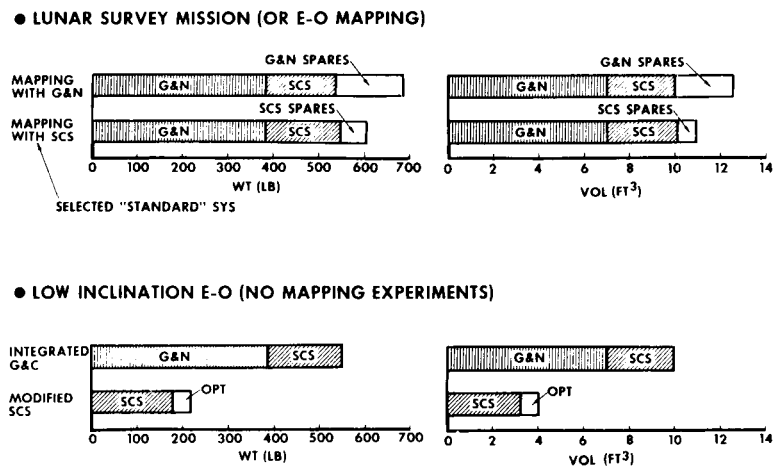

Figure 11. System Comparison

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addition of the boost monitoring function to the SCS would add approximately 40 pounds, as shown.

The Block II Apollo contains three fuel cells, which provide primary power to the spacecraft; all fuel cells are activated prior to launch and operate continuously throughout the mission. The Apollo X power loads average approximately 1700 watts for all missions, compared to the Apollo Block II loads which average approximately 2100 watts. The current Apollo fuel cell specification envelope, as shown in Figure 12, indicates that the use of three concurrently operating fuel cell modules for Apollo X would be marginal from the standpoint of staying above existing minimum power levels. Conversely, the use of only a single fuel cell would require power greatly in excess of the Apollo specification. To stay within the current Apollo fuel cell specification envelope, estimated Apollo X power loads require the concurrent use of two fuel cell modules.

Since the Apollo fuel cell specification is based upon a 400-hour qualification, more than a single pair of fuel cells will be required for Apollo X missions. Based upon a 50-percent confidence level in single fuel cell reliability and a desired overall confidence of 90 percent for the fuel cell system, five fuel cells are required in the Apollo X for both lunar and earth orbital missions. The operation of these fuel cells would be in pairs, with space startup required for three of the fuel cell modules, as shown in Figure 13. If 1.000-hour fuel cell modules (which have been proposed to NASA as a Block II change) are employed, a total of four fuel cells is needed. In either case, the Apollo X fuel cells would be operated in pairs, with startup of a new cell initiated at the time a currently operating fuel cell fails or degrades below acceptable limits. A number of methods can be employed for space startup of a cold fuel cell, including provisioning of an extra hot standby cell, use of primary or

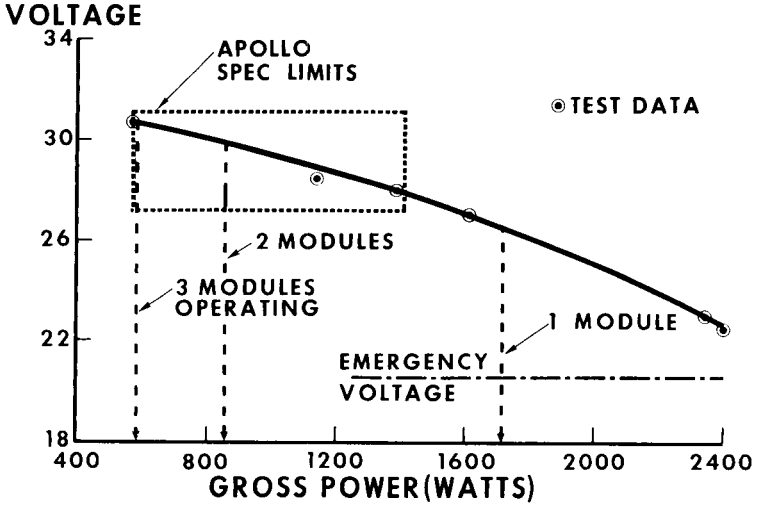


Figure 12. Apollo Fuel Cell Performance

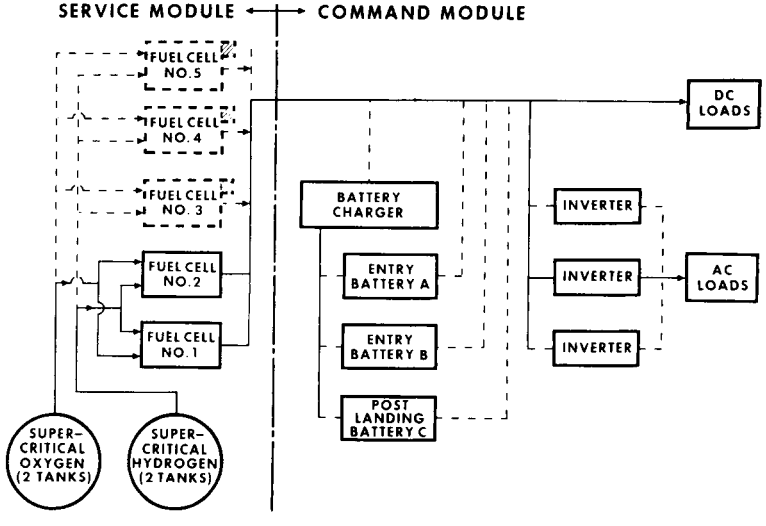
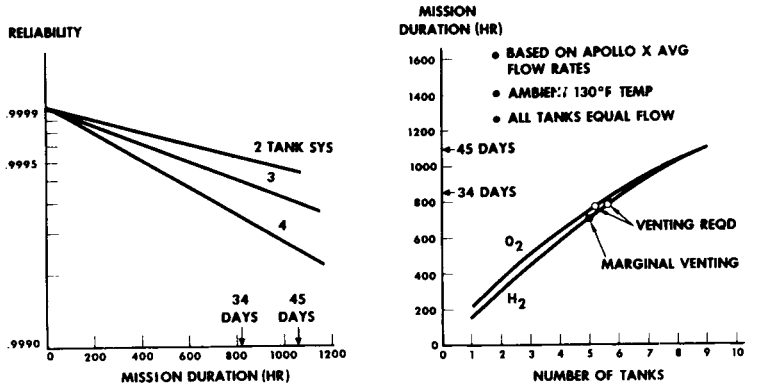


Figure 13. Apollo X Power System

secondary batteries, and either open- or closed-cycle catalytic reactors. The startup time and total system weight increments for each of these methods varies from 1/2 to 2-1/2 hours and from 39 to 264 pounds, respectively. On the basis of minimum complexity, however, the closed-cycle catalytic reactor is recommended; additionally it has a startup time capability of only 1-1/2 hours, with a total weight penalty of only 39 pounds.

The Gemini fuel cell has a demonstrated life of 1,000 hours but has disadvantages that require increased radiator area on the service module exterior (which is not presently available) and additional coolant pumps due to lower fuel cell operating temperatures. Therefore, the application of the Gemini fuel cells to Apollo X cannot be recommended at this time.

The Block II Apollo cryogenic storage system is made up of two pairs of hydrogen and oxygen tanks and provides fuel for the power system and metabolic oxygen for operation of the ECS. The Block II tanks are currently sized for the Apollo LOR mission duration, which does not exceed 14 days. The storage capacity can be increased by the addition of numbers of identical tanks as shown in Figure 14. However, system reliability degrades due to the number of switching functions involved. Increasing the number of tanks for durations greater than 33 days requires venting due to the boil-off problem. This results in an unacceptable storage method from a weight and volume standpoint, since nine or ten tanks are required for a 45-day mission. Therefore, from the standpoint of reliability, weight, and volume, one tank each of oxygen and hydrogen would be desirable. However, from a crew safety standpoint, two each are required because of the possibility of tank rupture occurring in lunar orbit. As a result, two identical tanks each



FLOW RATES (LB/HR)	APOLLO			APOLLO X		
	MIN	AVG	MAX	MIN	AVG	MAX
LH_2	.075	.17	.64	.10	.19	.21
LO_2	.67	1.45	3.85	.80	1.88	2.06

Figure 14. Apollo Cyrogenic System Application

of oxygen and hydrogen are provided, and are sized to accommodate 205 pounds of hydrogen and 2400 pounds of oxygen for the 45-day earth orbital missions.

The operating requirements for the service propulsion system (SPS) engine are well within the Block II Apollo capabilities with respect to number of starts, gimbal angle, and propellant required. Problem areas associated with the Apollo X missions are related to extended exposure in a space environment where cold welding, materials strength, and lubrication degradation could occur. Further qualification testing under simulated extended duration environmental conditions is required. The Block II SPS propellant tankage system concept is adequate for all missions. However, various tank sizes tailored to specific missions are desirable to eliminate adverse center of gravity locations and fuel slosh problems as previously mentioned. The current Block II SPS feed system is also adequate without change; however, further evaluation of the

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parallel feed concept should be made to provide more effective service module c.g. control.

The command module RCS provides small thrust levels for attitude control during reentry; this system is adequate without change for the Apollo X. The Apollo service module reaction control system (RCS) provides small thrust levels for spacecraft orientation changes, spacecraft attitude hold (during lunar mapping), and small amounts of acceleration for ullage prior to SPS firings. The number of cycles and total burn time required of the service module RCS engines are well within the qualification requirements of the current Block II Apollo specification. However, a thermal problem exists during the mapping portion of the lunar mission when the spacecraft must be maintained in a lunar-oriented attitude. The Block II Apollo RCS thruster thermal operating range is currently between 40 and 100 F. In the lunar mapping mission, all Apollo X RCS quadrants at some time fall outside of this operating range. Significantly, the problem is not specifically related to either the addition of heat or a requirement for cooling, but rather a requirement for both, depending upon orbit position. Therefore, an active thermal control system will be required for the service module RCS thruster quadrants on Apollo X. Attitude hold during the lunar mapping mission also dictates a requirement for larger RCS tankage capacities. The current Block II Apollo tankage contains 790 pounds of useable propellant. The Apollo X requirements vary from 1800 to 2200 pounds, depending upon the slewing rate and I_{sp} (steady state or pulse). Several solutions are possible, including the addition of a central make-up system that would feed all existing tankage quadrants, the development of new elongated tanks in each quadrant, the addition of a separate modular RCS installed on the laboratory module, or the use of multiples of existing Apollo CM, SM, or LEM tanks. The first two approaches are eliminated on the basis of volume availability and cost, respectively. The third approach is eliminated on the basis of interference by the RCS jet flame with the lunar surface to mapping camera line of sight. Consideration of the use of multiples of existing Apollo program tanks results in the selection of eight LEM oxidizer and fuel tanks (Figure 15).

OPERATIONAL IMPLEMENTATION. The Apollo X development planning was based on establishing a logical evolutionary development of extended earth orbital and lunar mission capabilities with maximum application of Apollo technology and hardware. In formulating the preliminary development plan, the Block II Apollo was assumed as the spacecraft baseline, and the Apollo Master Development Schedule No. 87, dated September 28, 1964, as the schedule base. Although this schedule has not been

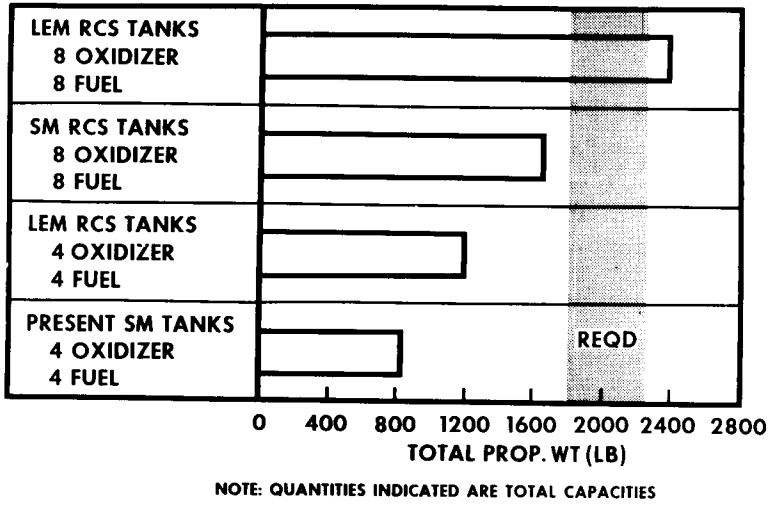

Figure 15. RCS Tank Combinations

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officially accepted by NASA, it is used internally by S&ID for Apollo development. It has also been assumed that a nine-month program definition phase (PDP) study will be conducted in calendar year 1965, which will yield spacecraft performance and preliminary subsystem procurement specifications, a complete development plan including the establishment of firm costs, and construction of mockups with an associated design engineering inspection (DEI). It is also assumed that design studies will have progressed sufficiently to permit 25-percent structural release within one month after initiation of the acquisition, or hardware development phase. A primary major constraint assumed in all development planning analyses is the assurance of noninterference with the Apollo lunar landing program. The term noninterference is interpreted to mean no perturbation of CSM delivery schedules or costs as well as placing no concurrent demand on existing government facilities such as Kennedy Spacecraft Center (KSC), the Manned Spacecraft Control Center (MSCC), etc. Study of the Saturn IB and Saturn V launch vehicle production rates was beyond the scope of the study, but it was conservatively assumed that the Apollo X development plan should be formulated such that none of these launch vehicles will be needed until all Apollo requirements for such boosters have been filled.

Development-qualification and system-development tests currently being performed in support of the Block II Apollo were used as a base for Apollo X test program planning. The primary purpose of these tests will be to qualify modified or existing hardware for the extended duration missions. A number of these tests will be oriented to assure that subsystem performance is not degraded due to the extended exposure in the space environment. For those systems requiring modifications, comprehensive testing will be accomplished in accordance with the building block concept where qualification tests will be performed at the component level by the subsystem subcontractors followed by system development tests at either subcontractor or NAA facilities. Subsequently, performance will be verified during integrated system tests, including simulation of mission environments. In all cases, test requirements will be based upon selection of the most severe mission for the subsystem involved.

The system ground tests are required to provide assurance and confidence that the mission objectives will be achieved. In general, test techniques and operation will follow those previously developed and now in progress for the Apollo program. Drop tests of a two-man Apollo X command module are planned to verify the redesign of the two-man crew couch and attenuation system. As presently planned, this test will be accomplished through the refurbishment and retrofit of Apollo Boilerplate No. 1 modified to the two-man Apollo X configuration. Although environmental tests of components and subsystems will be accomplished at subcontractor and NAA facilities, a complete space vehicle is planned for integrated systems testing under simulated space environment. This environmental test vehicle (ETV) will be the two-man configuration and will be subjected to approximately three months of testing prior to the initial Apollo X launch. These tests will be conducted in the thermal vacuum chamber at NASA MSC commencing in July, 1967. Present planning does not require an ETV for the three-man Apollo X configuration.

House spacecraft tests are based upon a requirement for two separate house spacecraft vehicles, including the two- and three-man configurations. The refurbishment time required precludes the possibility of modifying the two-man house spacecraft (3H-1) to the three-man configuration; therefore, a second house spacecraft (3H-2) is planned

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for the three-man configuration. House spacecraft testing will place primary emphasis on integrated systems tests. Simulated mission tests will also be included to contribute to the reliability data bank and to establish confidence levels in operation. Additionally, design modifications will be evaluated in the house spacecraft prior to implementation on the space mission vehicles.

Modal vibration acoustic tests are planned for house spacecraft 3H-1, which is the two-man Apollo X configuration. These tests, commencing in February 1968, will provide verification of structural integrity of the modified Block II Apollo configuration.

The Apollo X manufacturing plan is based on a production rate of one vehicle every two months which, when integrated with Block II Apollo deliveries at the same rate, results in a total production rate for both programs at one per month. A review of tooling requirements to support this rate indicates that no new primary structural tooling will be required, since previous Block I tooling requirements were based upon a one-per-month fabrication rate. The service module arrangements for the two- and three-man configurations are identical; therefore, tooling differences exist only between the two- and three-man CM configurations. These differences are minor and are attributable only to beef-up of the crew couch attenuator fittings. Detailed fabrication of the initial Apollo X manufacturing article (house spacecraft 3H-1) will begin in July 1966, which is one month after initiation of detailed fabrication for Apollo spacecraft 106, the first lunar landing vehicle (per MDS-8). Apollo spacecraft 107 through 112 will fly subsequent to the lunar landing mission, but do not yet have missions assigned.

The assembled command and service module structures enter the Bldg 290 complex (S&ID Downey) for systems installation and final preparation. The sequence of operations in Bldg 290 requires that four individual and combined systems checkout stations, three integrated systems checkout stations, and three house spacecraft stations are required to support integrated Apollo X and Apollo Block II schedules. The schedule in Bldg 290 can be maintained with only rearrangement of the stations after completion of the 90-foot extension currently under construction. However, some additional service equipment (SMD/GSE) will be required. As presently planned, the four programmed ACE stations will be adequate for support of this schedule.

Other existing S&ID facilities appear fully adequate for support of the Apollo X delivery schedule, with the exception of the bonding facility (Bldg 287). However, an addition of 28,000 square feet to Bldg 287 will alleviate this problem. The only facility changes exist in the form of rearrangements and include the CSM assembly area (Bldg 1), systems installation and checkout (Bldg 290), and the test and mission equipment area. All facility rearrangements, however, are regarded as minor.

The operation and checkout capabilities at Kennedy Spacecraft Center (KSC) will be required to support the integrated operations schedule shown in Figure 16. Facilities associated with the Vertical Assembly Bldg. and launch pads complex 39 (Saturn V) and complex 37 (Saturn IB) are considered adequate for the integrated Apollo and Apollo X programs. Present Apollo planning reflects availability of two ACE stations capable of simultaneously supporting three vehicles from initial checkout through launch. Since the integrated schedule indicates a period when a maximum of four vehicles are being prepared concurrently, one additional ACE station will be required to support this loading. The integrated operations schedule also reveals two occasions when the Manned Spacecraft Control Center in Houston will be required to support two missions concurrently, with the same requirement for the worldwide Manned Space Flight Net. This conflicts with present NASA operational philosophy which, in effect, precludes [redacted]

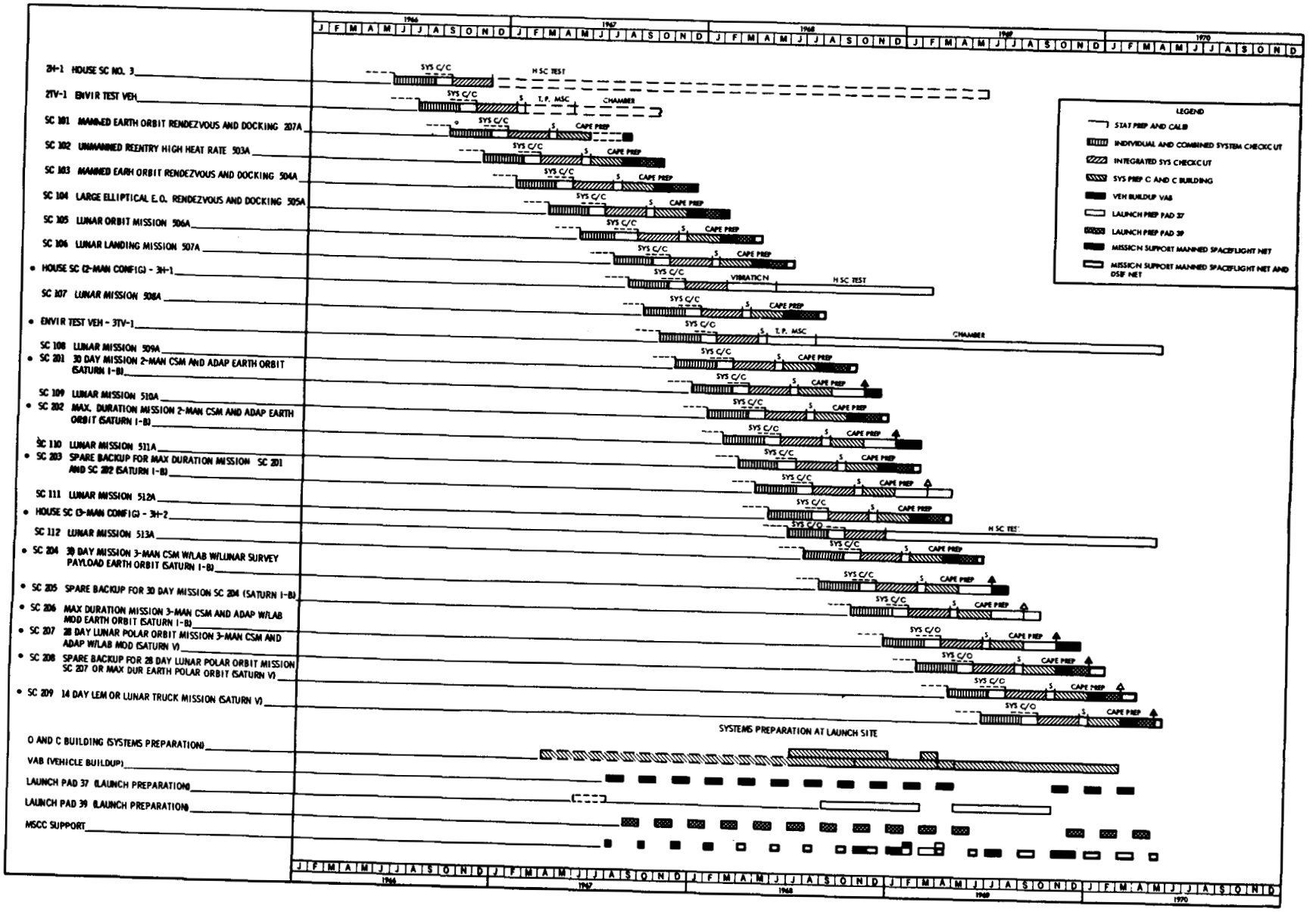

Figure 16. Integrated Operations Schedule

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simultaneous support of two manned space missions.

A total of 12 Apollo X vehicles is planned, as shown by the integrated operation schedule, Figure 16. Three of these are ground articles including house spacecraft 3H-1 and 3H-2 and the environmental test vehicle 3TV-1. The first Apollo X manned flight (SC201) will occur in November 1968. Apollo X spacecraft 201 and 202 missions will gather data regarding man's ability to perform and survive in the space environment as a prelude to later flights. Spacecraft 203 is planned as a spare vehicle or backup for spacecraft 202. Spacecraft 204 will carry the lunar survey payload in earth orbit for the purpose of substantiating its operation prior to the lunar survey mission. Spacecraft 207 is programmed for the 28-day lunar mapping mission and will be launched January 1, 1970. The data provided by spacecraft 207 would support the plan of spacecraft 209, which is programmed for an extended LEM or lunar truck mission. All spare backup spacecraft, if available, would be used to perform engineering and scientific experiments.

The total Apollo X program will cost approximately 430 million dollars, which includes the 12 previously mentioned vehicles but which does not include costs relating to the program definition phase study or post-delivery costs, such as field support at government facilities. Of the total program, manufacturing costs account for approximately 100 million dollars, of which approximately 27 million dollars is for material costs. When this material cost is combined with the subcontract and spares costs, approximately 234 million dollars or well over 50 percent of the total dollars would be expended outside of S&ID.

STUDY LIMITATIONS

Although each area of the Apollo X was examined in considerable depth, a number of limitations are evident due to conditions beyond the scope of the project. For those configurations with a separate laboratory module, the characteristics of the CSM subsystems are largely determined or influenced by laboratory module demands. For example, laboratory module weights, inertias, thermal loads, and power demands establish, to a great extent, the operating profiles and functional requirements of a number of the CSM subsystems. In view of the criticality of information of this nature to the Apollo X design studies, preliminary characteristics of the laboratory module were generated, although specific examination of the laboratory module was contractually outside of study scope.

All subsystems studies were based upon the Block II Apollo subsystems. At the time of study initiation, some of the changes being incorporated into Block II subsystem design had not yet been approved and, in some cases, may be quite extensive. For example, if NASA approves the 1,000-hour fuel cell as a Block II change, only four would be required for the Apollo X missions compared to the five 400-hour fuel cells presently estimated to be required. Limited allowances were made in the study for such possible alternate Block II changes.

IMPLICATIONS FOR RESEARCH

The life extension of the Block II Apollo vehicle and subsystems beyond the currently planned LOR mission duration will require additional qualification of modified Apollo hardware. This additional qualification will be concerned with not only substantiating extended mission operation, but also with evaluating the effects of extended duration space environment on various components. Since a number of the Block II Apollo subsystems will be modified by the addition of extra subsystems components, Apollo X qualification will be concerned with a number of tests performed on the complete modified

subsystems. However, other subsystem component qualification tests are indicated which result from component modifications (product improvement) and extended operation or storage in the space environment. Tests such as these have been identified and can proceed prior to formal Apollo X development.

The Apollo X earth landing system (ELS) will be subjected to extended storage in a cold vacuum environment for periods greatly in excess of the Block II Apollo ELS. Although redesign of the existing Apollo system is not required for the Apollo X, tests should be performed to determine the effects of extended space storage on textiles, lubricants, and pyrotechnics, and on cold welding characteristics of mechanical actuation system metal joints.

If a two-gas atmosphere is implemented in the Apollo X design, design and qualification of the inert gas storage and supply system and the cabin pressure control system is required. Other items -- such as radiator solenoid valves, improved suit compressors, a debris trap, and a catalytic burner -- have been incorporated into the Apollo ECS, primarily to permit high confidence level operation for extended missions. These additional components should be tested to further substantiate overall system reliability and operation.

The Apollo X two-man configuration (without separate laboratory) requires storage of 60 Apollo lithium hydroxide canisters in the command module for a 45-day mission. Although this would be operationally acceptable, the adverse weight and volume characteristics associated with this CO_2 removal method could be eliminated through implementation of a regenerable CO_2 removal system shown schematically in Figure 17. This would permit a weight saving of approximately 340 pounds and a volume reduction of 13 cubic feet. The system would employ two molecular sieves which would be alternately regenerated through exposure to the space environment. The regenerable system shown

	3 MEN (34 DAYS)		2 MEN (45 DAYS)		3 MEN (45 DAYS)	
	WT (LB)	VOL (FT^3)	WT (LB)	VOL (FT^3)	WT (LB)	VOL (FT^3)
APOLLO CARTRIDGES	297	10.6	261	9.3	396	14.1
MOLECULAR SIEVE + APOLLO CARTRIDGES	50	1.0	50	1.0	50	1.0
	54	1.6	9.0	0.0	9.0	0.0
GEMINI CANISTERS	—	—	>350	0.5 (CM) 11.0 (SM)	—	—

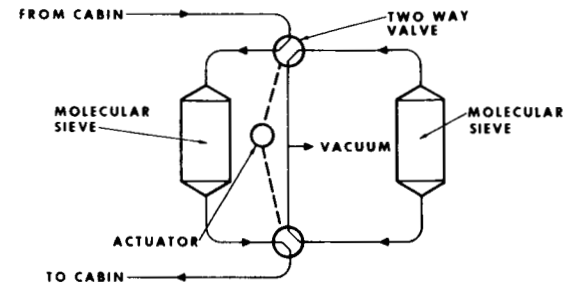

Figure 17. Regenerable CO_2 Removal

would be the first step toward development of more complex and larger systems required for large, extended duration (greater than one year) space stations. Such a system has already been brought to the breadboard stage by several companies engaged in environmental control system research and development. The regenerable CO_2 system would be a desirable, but not required, modification for the Apollo X.

In order to fulfill Apollo X operating and life requirements, the fuel cells must be operated in series fashion; i.e., when one cell fails, in-space startup of a cold standby cell is required. Since current Apollo operation is based upon startup of all cells prior to launch with mission abort required after failure of one or two fuel cells, the in-space startup capability does not now exist and must be developed for the Apollo X missions. This requirement was revealed in previous studies; Pratt & Whitney (the Apollo fuel cell manufacturer) is currently performing a separate study of space startup methods under sponsorship of NASA MSC

[redacted]

There are a number of problems attendant with operating the service module RCS in the Apollo X operational profile that result in deleterious effects upon the tankage expulsion bladder. The number of cycles required results in compound folding of the bladder which reduces expulsion efficiency. Studies have indicated that reducing expulsion helium pressure to 2 psi and accepting an efficiency degradation below current Apollo Block II specification limits will overcome this problem. However, tankage tests under these conditions are warranted. Bladder permeation presents a problem for Apollo X durations in which a transfer of the pressurant helium and propellant occurs across the bladder due to differences of molecular concentration. Tests should be performed to verify bladder permeation characteristics. If a low level of permeation exists, additional propellant or helium could compensate for these losses. However, if the tests indicate the permeation to be significant, a new bladder design must be investigated, such as a multiple ply bladder in which venting would be provided between the plies. Tests should also be performed to indicate teflon bladder membrane degradation resulting from extended exposure to propellants. If these test results are negative, improved bladder materials should be investigated through further testing.

SUGGESTED ADDITIONAL EFFORT

Studies of life extension of the Apollo spacecraft have progressed to the point where the characteristics of the extended life subsystems are well defined. It is believed that the next logical step would be the accomplishment of a program definition phase whereby a plan can be formulated for implementing required spacecraft and subsystem changes into an integrated overall program that would result in orderly development of the Apollo X vehicles. Further, the studies to date have indicated that a number of separate, though related, investigations are now in order.

The performance of manned, earth polar orbital missions will be difficult to achieve under present NASA range safety constraints for Cape Kennedy launches. The current range safety limits at Cape Kennedy preclude the possibility of delivering any payload to polar earth orbit with the Saturn V launch vehicle. Further detailed study is warranted to examine the validity and/or rigidity of current range safety constraints to establish possible alternate methods for satisfactorily implementing the Saturn V launch vehicle for future manned polar earth orbital payloads.

The operational philosophy currently employed by the NASA Manned Spacecraft Control Center (MSCC) effectively prohibits integrated scheduling of Apollo and Apollo X flights. Although a possible solution exists whereby Apollo X flights would be delayed until all Apollo flights have been completed, it is believed that the MSCC capability should be increased in order to handle future simultaneous flights attendant with the expanding national space program. In particular, studies should examine the operations and additions required for this capability at the MSCC in Houston and the network stations, including ground communication links.

The purpose of the early Apollo X flights will be to gather data relevant to man's ability to survive and perform in extended space missions in order to provide a high confidence base for performing subsequent Apollo X and other extended duration missions. Studies dealing with biomedical and human factors experiments have progressed sufficiently so that the next study phase could result in the definition of experimental equipment specifications. Since experiments of this nature will receive early emphasis in the Apollo X program, immediate study effort should be devoted toward definition of these equipment specifications. Included should be studies dealing with vehicle integration aspects such as storage volume requirements, crew operations, and experimental plans.

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