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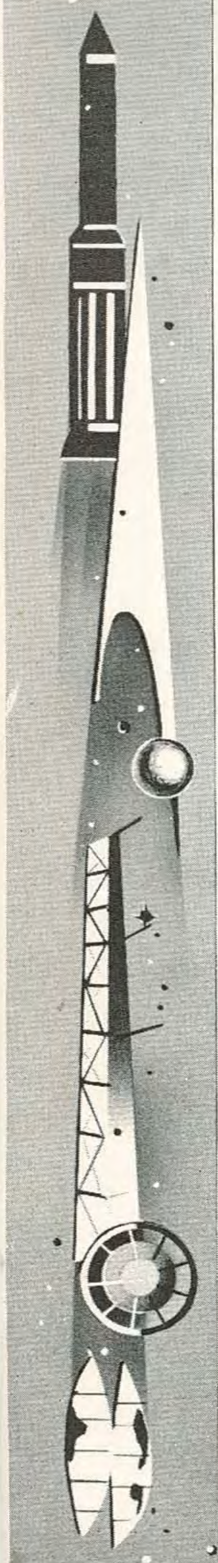

SOME APPLICATIONS OF APOLLO

by

George E. Mueller

Associate Administrator for Manned Space Flight

National Aeronautics and Space Administration

Washington, D. C.

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GEORGE C. MARSHALL SPACE FLIGHT CENTER

SOME APPLICATIONS OF APOLLO

The Gemini and Saturn/Apollo programs are providing the U. S. A. with a broad base of technological, managerial, and resource capability which makes feasible a wide spectrum of space missions beyond the initial lunar landings. These manned missions can be exploited in a wide range of Earth orbits, in lunar orbits, and on the lunar surface. In particular, the flexibility of the Apollo system, as presently in development, makes feasible an extended duration Earth-orbital program which can serve as the essential precursor for advanced Earth-orbital laboratories as well as a test bed for developing the techniques and operational experience necessary for longer-range lunar and planetary exploration.

Gemini/Apollo Capabilities

The Apollo hardware has now been defined, and is entering an intensive ground and flight test phase. Therefore, it is both possible and timely to define spacecraft configuration and flight plans, using this same hardware, to carry men and instruments into hitherto inaccessible regions of space for hitherto unachievable periods of time. The scientific and technological objectives which could thus be achieved may well lead to new ventures in future decades which are as far beyond Apollo as the lunar landing mission itself will be beyond the first manned Earth-orbital flights.

The U. S. inventory of tested space hardware by 1970 will include three man-rated launch vehicles: the Titan II, capable of placing 4 tons in Earth orbit; the Saturn IB, to place over 18 tons in orbit; and the Saturn V, to inject 140 tons into near-Earth orbit and more than 45 tons into a translunar trajectory. The Gemini spacecraft supports two men in low-Earth orbit for up to two weeks and has the capability of some 300 ft/sec of in-orbit velocity change. It will carry several hundred pounds of experiments initially and can be resupplied with considerably more through docking with an Atlas- Agena rendezvous vehicle. Extra-vehicular activity (EVA) has been successfully demonstrated from the Gemini spacecraft.

The Apollo/LEM spacecraft to be launched by the Saturn vehicles will: sustain a three-man crew in space for from two weeks to six weeks; provide a two-room, three-stage mobile space station capable of extensive space maneuvers as well as landing on the Moon and returning to Earth. On the ground, the Apollo system will include highly-automated checkout and launch facilities, together with a world-wide network of tracking and communication stations linked to central computer and mission control facilities. The inventory will also include a vast complex of industrial and government facilities, manned by highly-skilled and experienced teams, which can produce flight-ready Saturn/Apollo space vehicles at a rate of more than eight per year. Last, but not least, by 1970 there will be many highly-trained and flight-qualified U. S. astronauts, including scientists, engineers, physicians, and test pilots to man the spacecraft and perform a wide variety of space flight experiments.

With these assets within our grasp, it is now possible to plan for the application of the Apollo hardware to a wide variety of experiments in the areas of science, biomedicine, technology, and operations and to define the mix of missions which would bring together the Saturn/Apollo space vehicles, experiments, and the trained crews required to carry out these experiments. This effort, including both extended Earth-orbital and lunar missions, is embodied in the proposed Saturn/Apollo application program now undergoing preliminary program definition. The design of experiments and missions has been such as to capitalize on the capabilities of man as a trained observer, who can determine what to look at, how to observe it, and of what importance the results are. In this way the best use can be made of the weight available to return data to Earth, and to avoid returning redundant or uninteresting data. In the course of the mission, the observer can aid in determining which measurements are of most value and thereby affect the payloads of future missions.

Apollo Applications

Studies have confirmed the feasibility of exploiting the investment in the Apollo program by applying its wide range of capabilities to a number of other potential missions and accomplishing these without interfering with the primary Apollo lunar landing goal. In this extension of the Apollo program, the basic consideration has been to use present Apollo hardware with as little modification as is consistent with the proposed mission under study. Our examination shows that, with the inclusion of added expendables and different experiments, a number of missions in Earth-orbit, lunar-orbit and on the lunar surface can be accomplished with the present Apollo launch vehicles and spacecraft.

The basic Apollo system, as shown in Figure 1 in its launch configuration, is designed to accomplish three basic missions: Three-man flights in Earth-orbit for 10-14 days, three-man flights which orbit the Moon for four to six days, and landing two men on the Moon for 24-36 hours. The first two types of missions are planned to support the third one -- the national goal of manned lunar landing.

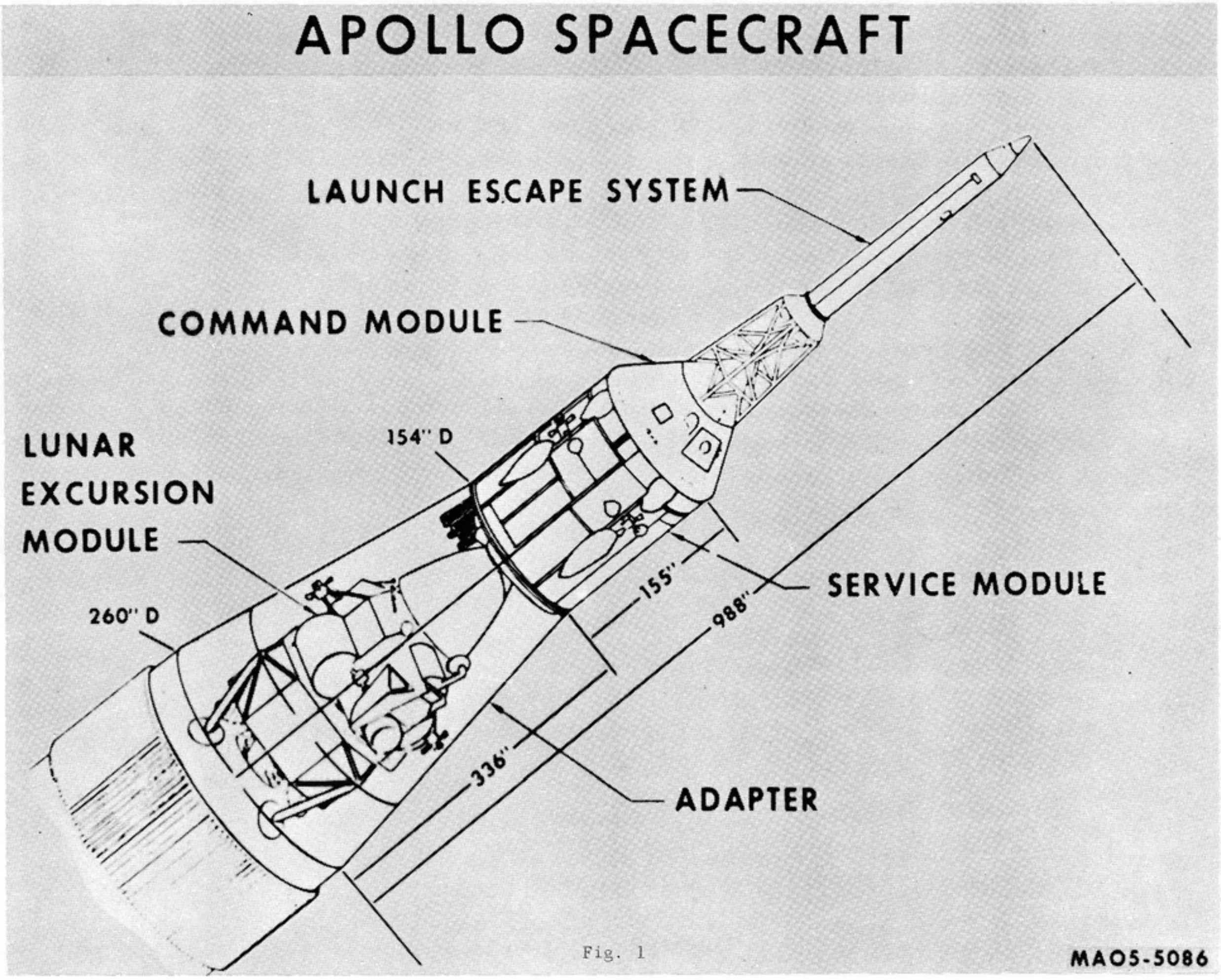


Fig. 1

The extension of the Apollo capabilities now being studied encompasses Earth-orbital, lunar-orbital and lunar-surface missions. The Earth-Orbital missions include extended durations in low-inclination, polar, and synchronous orbits. Flights of up to 28 days in lunar polar orbit and lunar surface missions of two men for up to 14 days are possible.

The basic Apollo spacecraft, consisting of the command and service modules and the LEM, has an inherent potential for increased capability to conduct in-flight experiments. Considerable flexibility is available to meet the requirements of various missions. For extended Apollo missions in Earth orbit the propellant loading of the Saturn IVB stage (the third stage of the Saturn V vehicle) and the Service Module can be varied so that space maneuvering capability may be traded for additional experiment load-carrying capacity. Further, the adapter section, shown in Figure 2 with a LEM inside, encloses almost 6,000 cubic feet of unpressurized volume. This volume can be used to carry other large experiment payloads such as an astronomical telescope or for an erectable structure such as an antenna for communication experiments or radio astronomy measurements.

CUT-AWAY VIEW OF SPACECRAFT LEM ADAPTER SHOWING THE LEM INSIDE

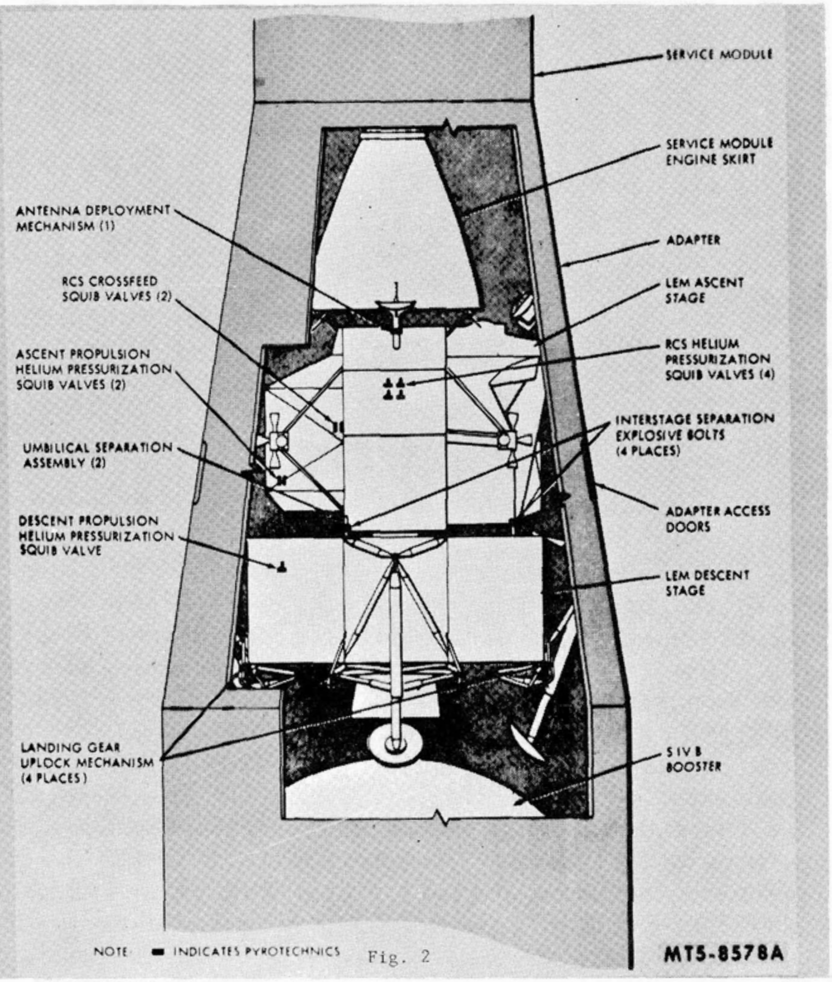


Fig. 2

APOLLO SPACECRAFT FOR ORBITAL MISSIONS

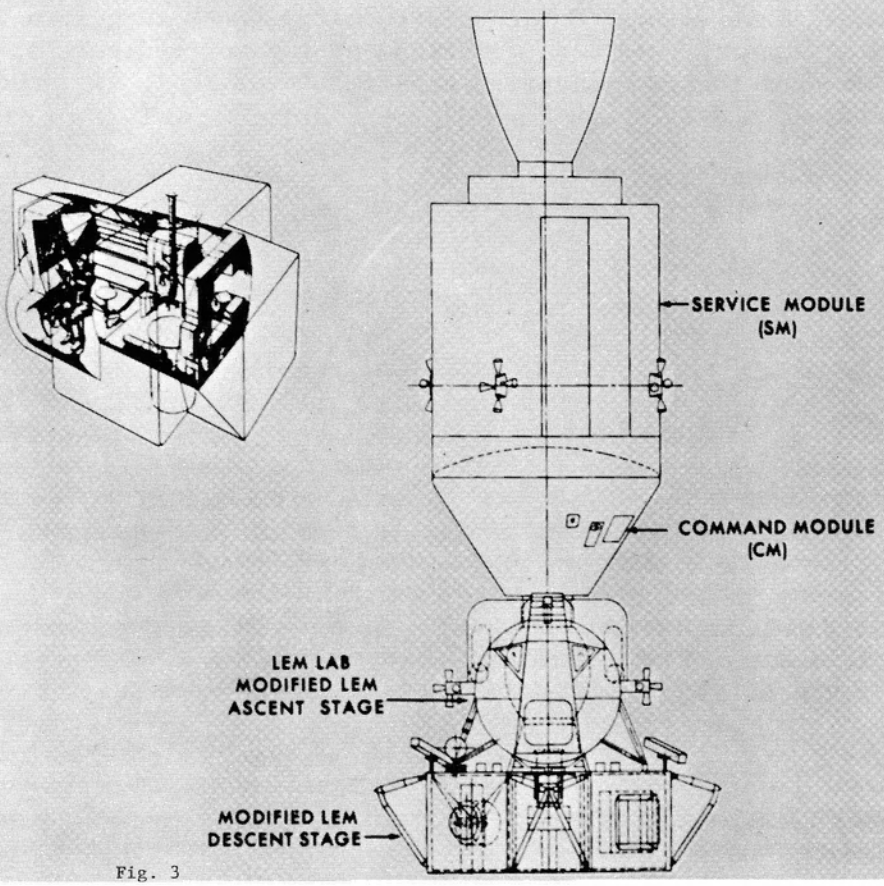


Fig. 3

The engineering sketch of Figure 3 shows one version of an extended Apollo spacecraft configured for Earth-orbital or lunar-orbital missions. The LEM-descent stage structure and propulsion systems are unchanged, but the landing gear has been removed since it would not be required for orbital missions. The remaining LEM propulsion can be used to supplement the service module propulsion for orbital maneuvers. The experiment equipment will be installed primarily in the available unpressurized sections of the descent-stage structure, inside the LEM cabin, and around the outside of the ascent-stage pressure shell. The LEM-ascent-stage main propulsion system, including engine, propellant tanks and associated gear, can be removed to provide greater capability for experiments if necessary. Over 200 cubic feed of laboratory space could be available within the LEM ascent

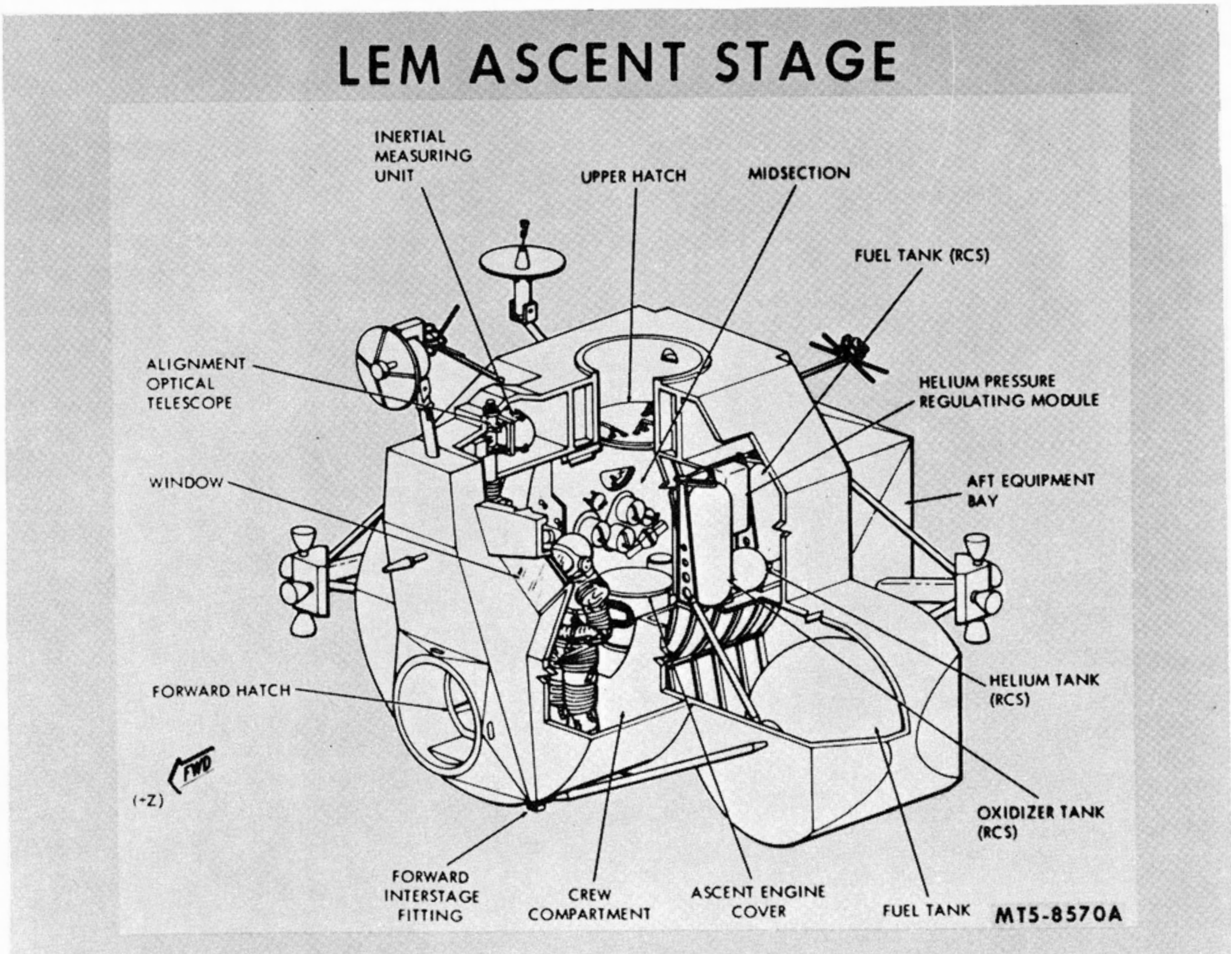
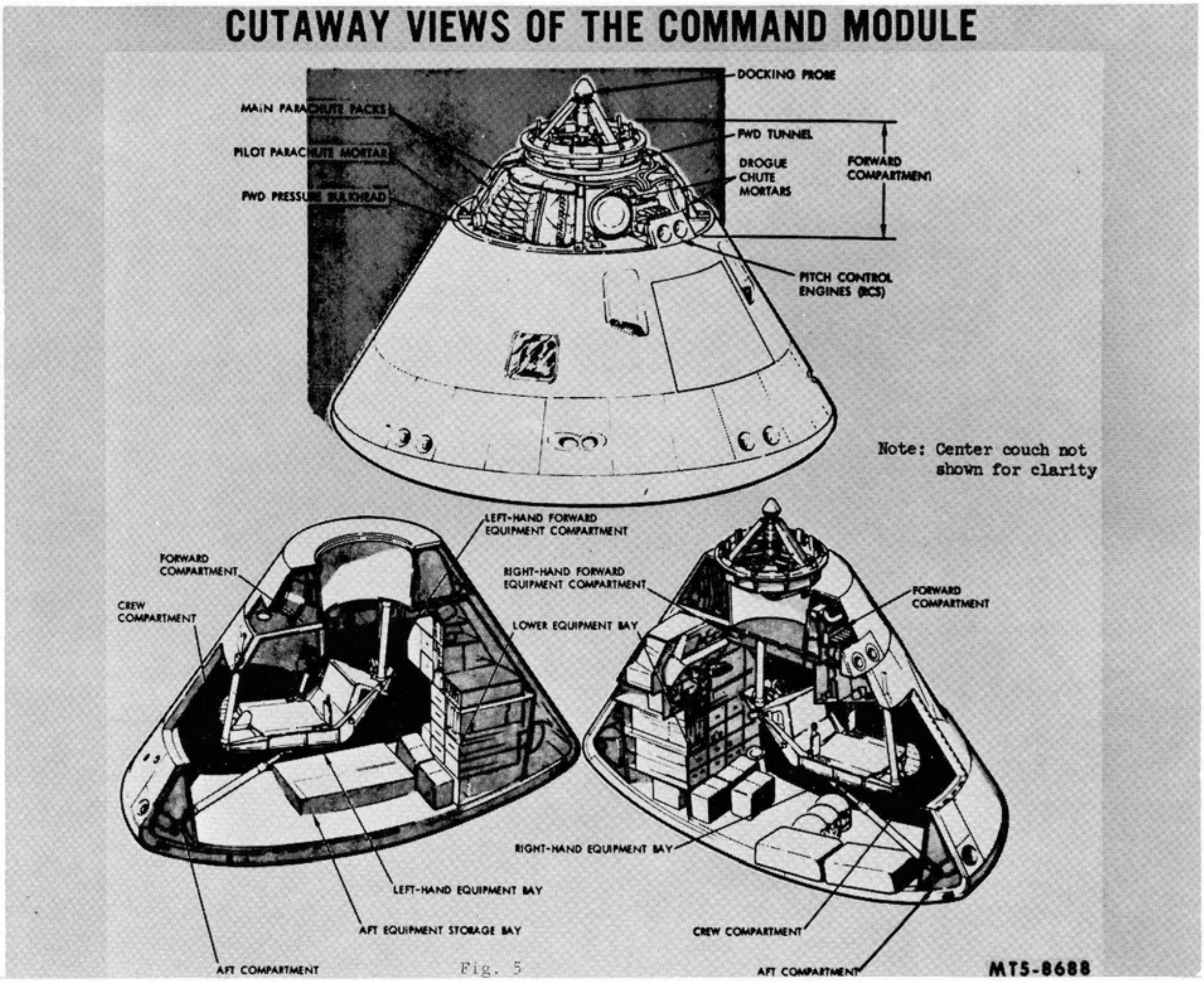


Fig. 4

stage shown in Figure 4. Additional power and life support expendables to permit long-duration flights will be added.

The Command and Service Modules (CSM) shown in Figures 5 and 6 are essentially those used for the basic Apollo lunar-landing mission. With this system, separate and independent operation of the CSM and the LEM is possible in orbit, using the LEM descent stage and the Service Module propulsion systems to effect subsequent rendezvous and docking. Extra-vehicular operations can be undertaken by astronauts in their spacesuits. In this mode the LEM would serve as an air lock, with exit and entrance through the LEM-ascent-stage external hatch.

Section 1 of the Block II Service Module has been kept empty to accommodate experiments, and designs have been made to utilize this space. One such concept is called the Experiment Pallet. This pallet, shown in Figure 7, occupies 210 cubic feet of unpressurized space, is structurally limited



Note: Center couch not
shown for clarity

Fig. 5

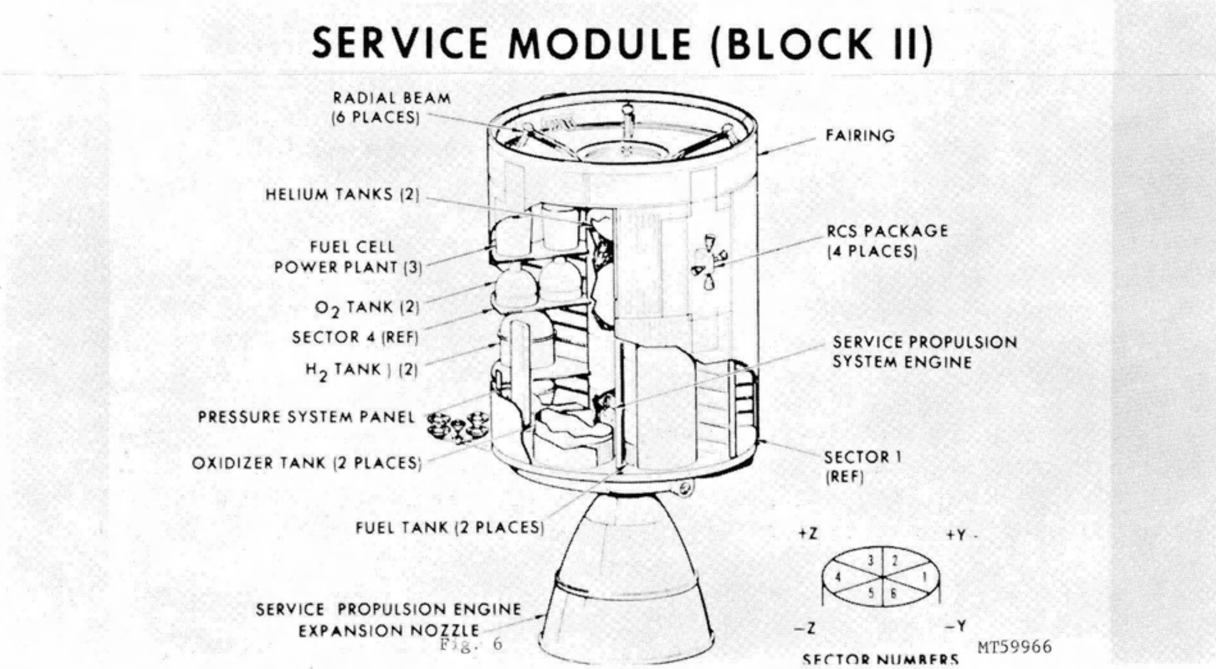


Fig. 6

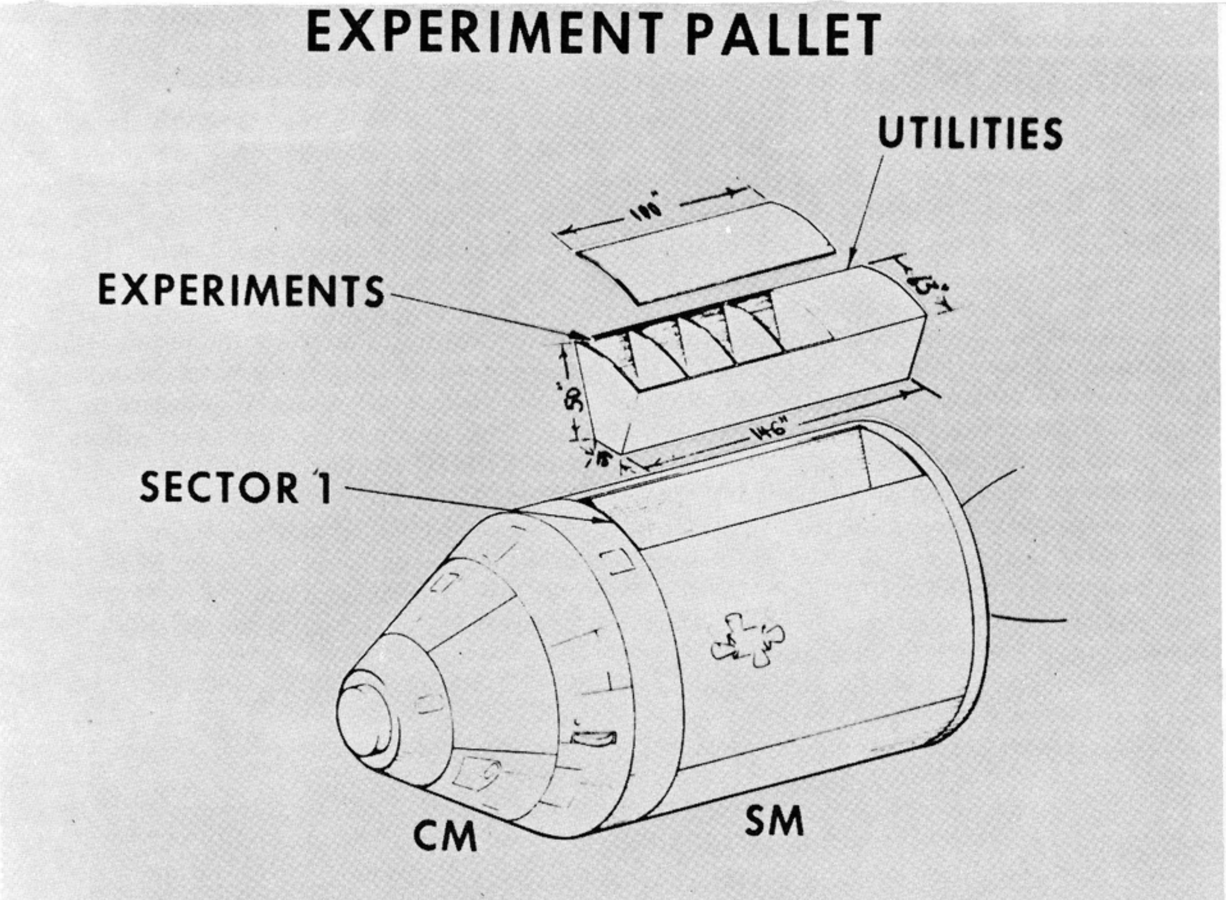


Fig. 7

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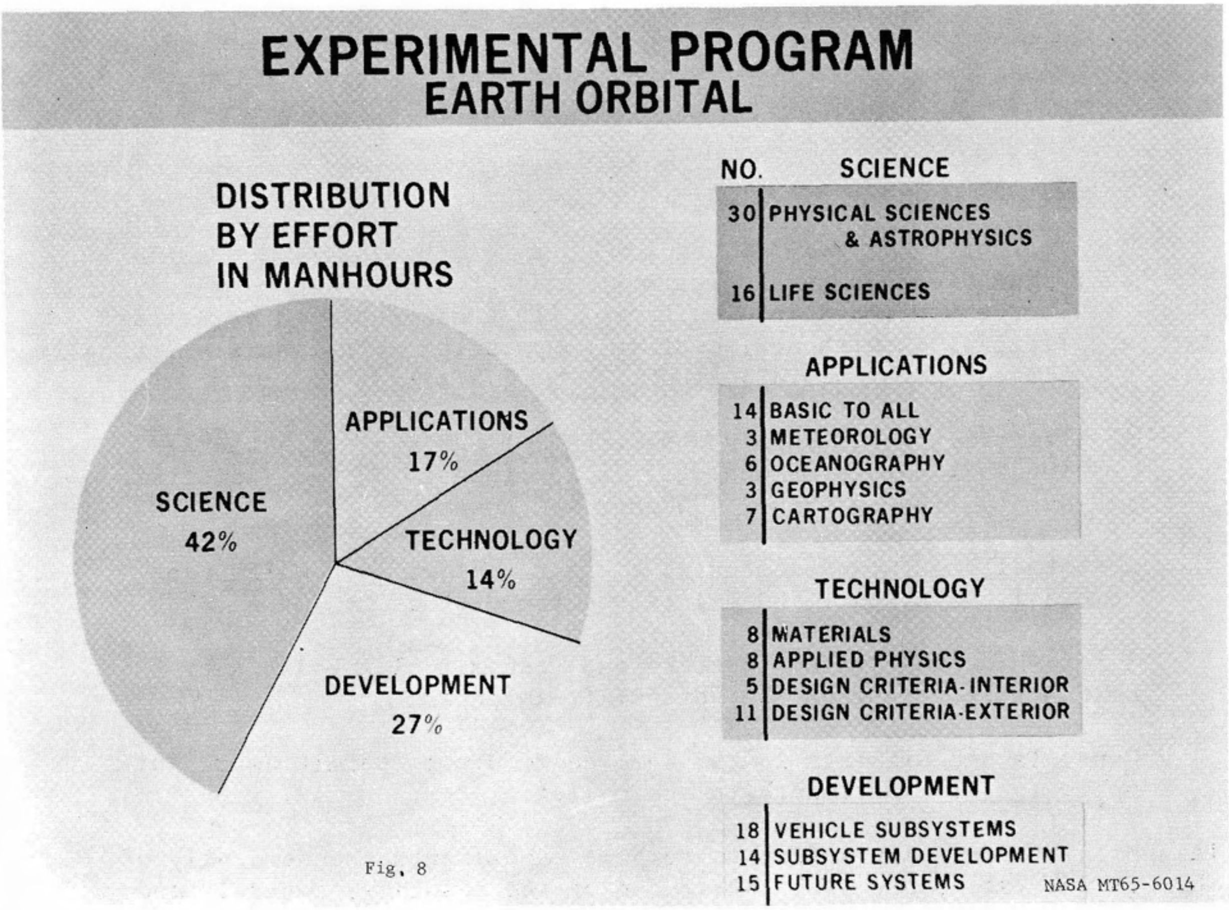
to 5,000 lbs. of total weight, and can carry experiments and associated support equipment. Design studies have indicated that approximately 3,500 lbs. of experiments in a volume of 115 cubic feet can be carried in the pallet, along with equipment to support the experiments. Typically, this support equipment would include:

> An electrical power supply consisting of 400 lbs. of batteries supplying 35 Kw-hr. of energy. In addition to 28 d-c, inverters can supply 115v, 3 phase, 400 cps. a-c power.
>
> A thermal control system using a water cooling loop which can remove 1,600 BTU/hr. and maintain a temperature of 70° ± 25°F.
>
> A data-handling system to store and transmit 51.2 kbits/sec. of PCM telemetry from the spacecraft antennas.
>
> Controls and displays in the Command Module to permit astronaut operation of experiments in the pallet.

This pallet offers a platform to support experiments independently of the CSM subsystem, but with interfaces on the displays, controls and communications.

Some of the Earth-orbital experiments that have been studied are summarized in Figure 8 where they are divided, for convenience, into four categories -- space sciences, Earth-oriented applications, technological investigations, and development of space operations. It should be noted that the categories are made in terms of the objectives rather than the equipment required for any particular experiment, since a qualified piece of equipment can be utilized in more than one of the categories.

Based on preliminary studies, nearly 200 meaningful Earth-orbital experiments have been identified; in Figure 8, 170 of these have been analyzed by category to show a typical distribution of time in manhours required to conduct experiments in flight. The associated outline shows the numbers of experiments in each category. Only a year ago the number of manned experiments identified totaled less than 100. It seems reasonable to assume that, as our knowledge and interest in space grow, the numbers of experiments will continue to grow and even exceed our increasing payload capability. The larger manhour effort in science -- 42% of the total -- is indicative of potential opportunity for scientific research in orbital laboratories.



EXPERIMENTAL PROGRAM
EARTH ORBITAL

DISTRIBUTION BY EFFORT IN MANHOURS

NO.	SCIENCE
30	PHYSICAL SCIENCES & ASTROPHYSICS
16	LIFE SCIENCES
	APPLICATIONS
14	BASIC TO ALL
3	METEOROLOGY
6	OCEANOGRAPHY
3	GEOPHYSICS
7	CARTOGRAPHY
	TECHNOLOGY
8	MATERIALS
8	APPLIED PHYSICS
5	DESIGN CRITERIA-INTERIOR
11	DESIGN CRITERIA-EXTERIOR
	DEVELOPMENT
18	VEHICLE SUBSYSTEMS
14	SUBSYSTEM DEVELOPMENT
15	FUTURE SYSTEMS

Fig. 8

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One interesting result of this study of experiments is that many of them can utilize common equipment. By good planning and scheduling, considerable economies in equipment costs and in numbers of flights required can be achieved. For example, the same telescopic optics can be used for imaging and for spectographic analyses. Similarly, the multi-spectral sensors and, perhaps the radar or micro-wave detection equipment, which might be used for examining agricultural areas and forests, could also be adapted to the various problems of oceanography and traffic monitoring on the seas. For the nearly 200 experiments presently identified for Earth-orbital missions, commonality of equipment could reduce the total orbited payload weight by a factor of more than three.

A selection of some 85 of these experiments has been used as a basis for preliminary definition of 12 Earth-orbital mission types. These are described in Table 1 (omitted). Regimes for these missions range from low-altitude, low-inclination flights yielding the maximum payload weight from the Saturn IB to polar and synchronous orbits using the Saturn V.

Illustrative Missions

The possible scientific and technological objectives of Earth-orbital missions may be grouped in various ways. I have chosen as illustration four examples of mission grouping which cover the following primary objectives:

(1) Astronomy
(2) Bioscience/Physical Science
(3) Earth-Oriented Applications (Remote-Sensing)
(4) Space Operations/Technology

These typical missions are described below with illustrative experimental payloads. The experiments discussed in these sample missions were defined by NASA for purposes of study only. They are considered typical of experiments which might be proposed by the scientific and technological communities for flight on 45 to 90 day extended Apollo Earth-orbital missions.

Astronomy Missions

The objectives of these missions are to perform both radio and optical astronomical observations at orbital altitudes above the impeding layers in the Earth's atmosphere and ionosphere. The orbital vantage point would allow optical astronomy free of atmospheric distortion; and it would allow radio wave-length observations to be extended below 1 cm, where atmospheric absorption due to oxygen and water vapor begins, and above 30 meters, where reflection of longer waves in the ionosphere takes place.

The payload for the astronomy missions could be composed of an optical telescope with suitable filters, cameras, etc. to operate in both an imaging and spectrophotometric mode; a radio-telescope to measure radio wave flux and spectral properties at wavelengths of 30 m or greater; and a space radiation telescope to measure cosmic ray and gamma ray flux and energy spectra.

A typical astronomy mission would be in an Earth-synchronous orbit of altitude 19,350 NM and inclination 0^{o}. The duration is 45 days, with a crew of three.

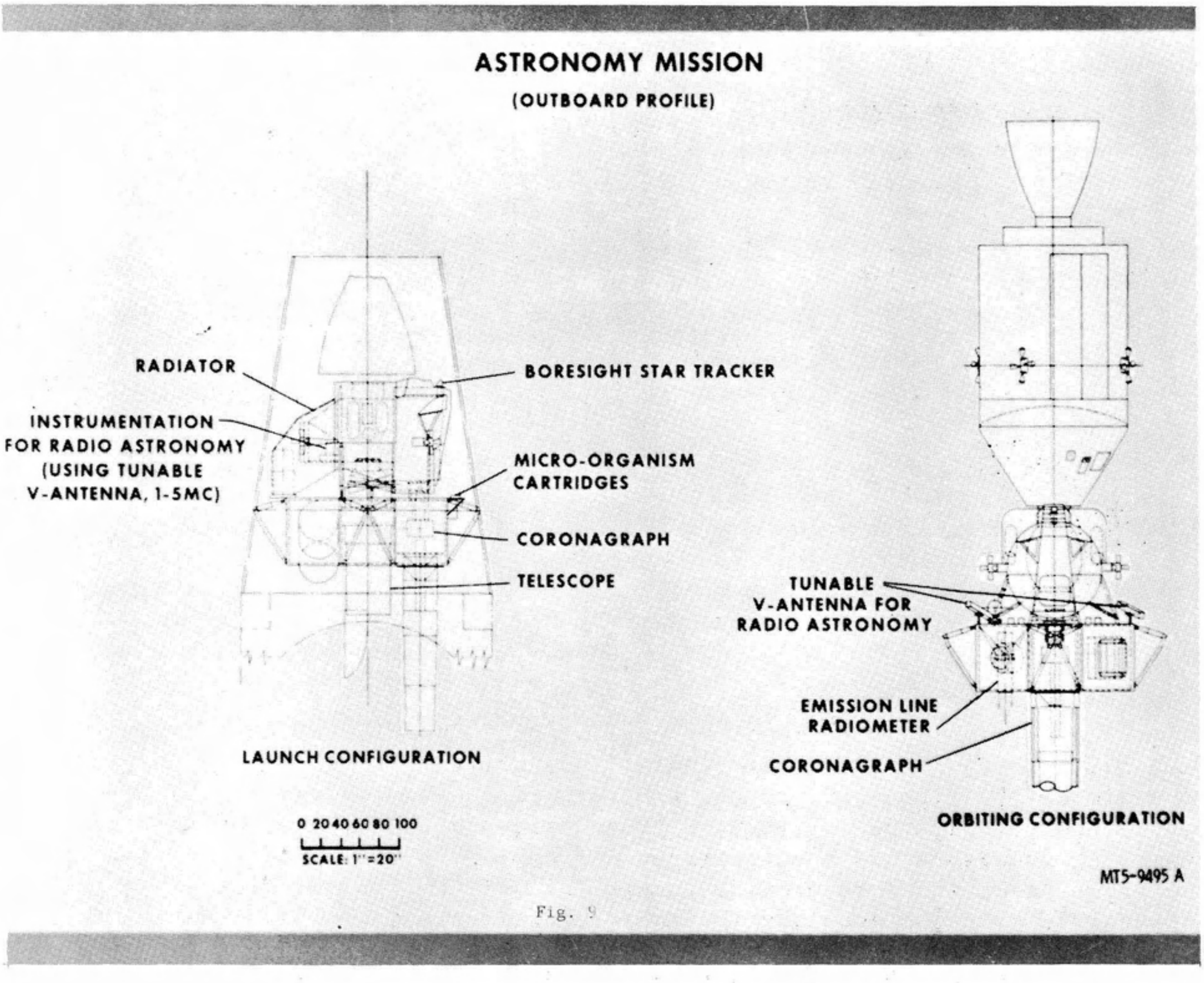
This mission has been planned primarily for astronomical experiments, which will obtain spectral and photometric data in the x-ray, visual and infrared portions of the spectrum from various points of interest throughout the celestial sphere. These points consist of either discrete stellar sources or diffuse patterns of interstellar media, plus a period of Earth-pointing experiments for conjugate aurora observations.

There has also been included a secondary array of experiments consisting of observations of living organisms exposed to the space environment, a deployable maneuverable satellite, an extendable antenna rod for radio astronomy measurements, and a deployable communications satellite (passive) in the form of a solar sail. The selection of the secondary experiments was based on their lack of definite pointing requirements. Hence, any conflict with the pointing requirements of the primary astronomical experiments will be minimized.

In order to achieve the most advantageous viewing conditions throughout the 45-day mission for the primary astronomical experiments, the spacecraft is injected into a synchronous orbit (19,350 NM alt.) and positioned over ground facilities compatible with the requirements of the mission. One day is given to set up of the various experiments. EVA's are necessary for retrieval of the micro-organism specimens and "redocking" of the small maneuverable satellite.

The space vehicle consists of a Saturn V launch vehicle, an extended CSM, and a LEM-Lab with ascent and descent stages. The experiments carried are summarized in Table 2 (omitted) giving equipment location and weight.

The spacecraft for this mission is shown in Figures 9 and 10. Nominal spacecraft attitude is inertially oriented. Attitude is held within a deadband of ± 5° except during experiment periods having specific pointing and stability requirements. Experiment pointing and stability requirements exceeding CSM capability are accommodated by installing the experiment telescopes on gimballed mounts and providing fine guidance and control systems within the telescopes.


ASTRONOMY MISSION

(OUTBOARD PROFILE)

Fig. 9

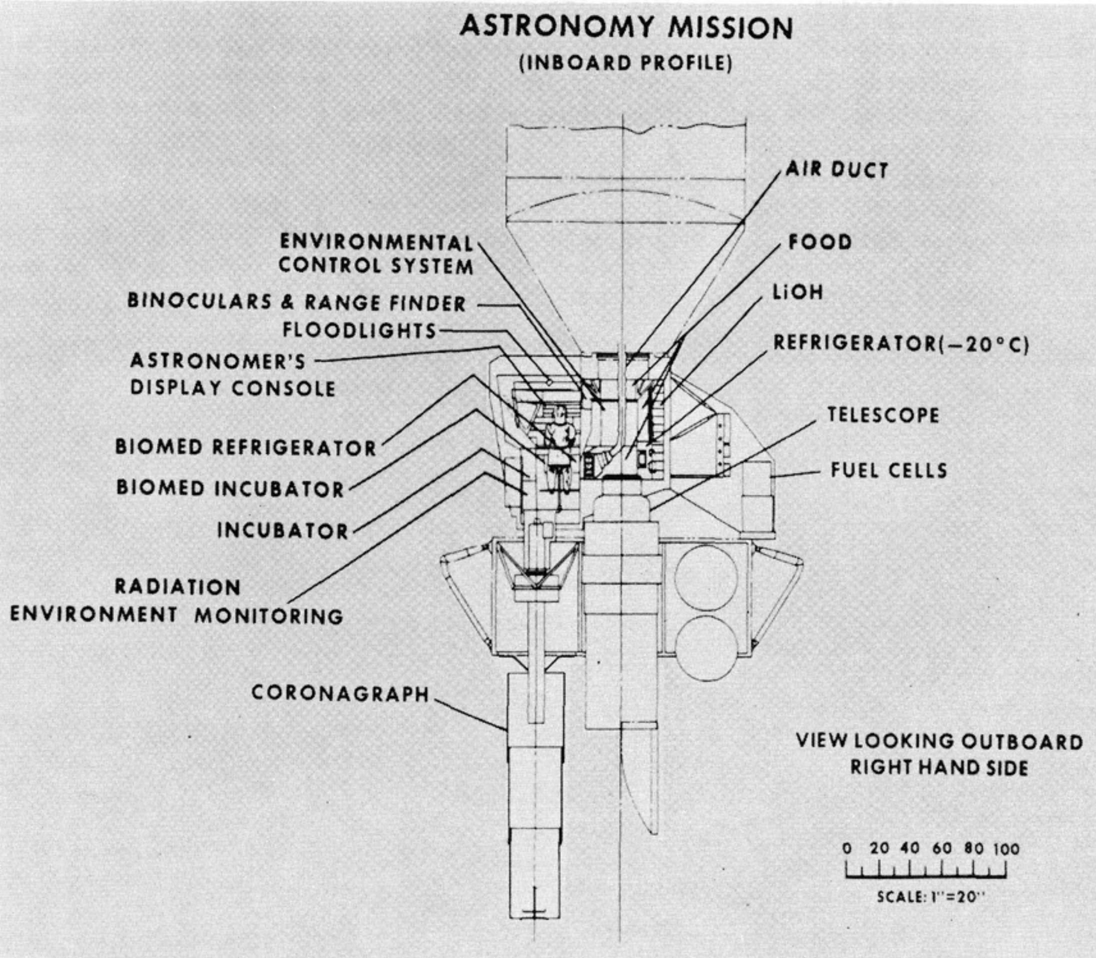


Fig. 10

The astronomy experiments are all aligned parallel to the longitudinal axis of the spacecraft and are controlled from an astronomer's console on the right side of the LEM forward cabin. Access to the telescope and coronagraph is provided from inside the LEM for readily changing cameras, magazines and spectrographs. A common TV view-finder and two boresight star trackers provide inputs for orientation and control. Spacecraft pointing accuracy for these experiments is ±0.5°. The telescopes, coronagraph, and conjugate aurora experiments are gimballed and incorporate fine error sensors to meet individual requirements.

A control console on the left side of the LEM forward cabin is used for the space structures, conjugate aurora, and subsatellite experiments. All food for the mission is stored internally. A 7-day supply of LiOH is stored internally and is replaced during scheduled extra-vehicular activity from external storage.

Externally, the space structures technology, conjugate aurora, and maneuverable subsatellite are checked out; the latter is launched from, and recovered by, its launch package mounted on the rack. The subsatellite is refueled and its film obtained during EVA.

Supporting electronics and spares for experiments are carried in the aft equipment bay of the Ascent Stage. Structural modifications to the LEM Ascent Stage are limited to the incorporation of an airlock below the floor panel in the forward cabin to accommodate the coronagraph. The telescope airlock is designed to mount in the existing ascent engine hatch. The Descent Stage structure must be reworked to accommodate the coronagraph.

In addition to the standard CSM/LEM interface, this flight requires additional wiring to accommodate the pointing requirements of the experiments. Interface wiring includes star tracker inputs to maintain attitude hold and command data for the flight controller for manual control of spacecraft slewing operations.

This flight utilizes an Apollo CSM fuel cell electrical generation system, a LEM environmental control system (ECS) to provide suit circuit operation in the Lab during EVA, and selected components to provide data transmission, status and appropriate displays.

The large number of rotational maneuvers required by some of the experiments, together with the gravity gradient distrubance torques, create large reaction control system (RCS) propellant requirements. Therefore four sets of LEM RCS tanks are carried in the service module.

Bioscience/Physical Science Laboratory Missions

The goal of these missions is the determination of the effects of extended periods of weightlessness and the development of techniques to counteract those effects which are adverse to man's well-being. Such investigations are a necessary step in preparing for extensive use of man in space. The extended Apollo not only permits extending man's time in space but provides the capability for including trained medical observers on the mission and for using various means of therapy to counteract any adverse effects of space flight.

Two of the major areas of interest are the effects of weightlessness on the cardiovascular and musculoskeletal systems. Short-time experience to date indicates potential problems such as arterial deconditioning and loss of calcium from the system. However, such symptoms could result from several causes; therefore, a well-controlled series of experiments must be carried out to determine the causes and effects. It is necessary to establish the most significant set of measurements which can be made to monitor adequately the long-term effects of weightlessness and to select the most compact instrument package to make these measurements.

With the capability of Apollo, it should also be possible to investigate various means of therapy for undesirable space effects if they should occur. Such therapy may be relatively simple, such as exercise, or might involve the creation of an artificial gravity environment.

In addition to biomedical/behavioral experiments, it should be possible to carry out on these missions a nember of fundamental experiments to observe the effect of the absence of gravitational forces on physical, chemical and life processes. Examples of some of these experiments are as follows:

(a) Physics - a measurement of extremely small physical effects on test bodies, such as light pressure and recoil reaction during radioactive decay.

(b) Physics - observation of relativistic precession of a gyroscope during spacecraft orbit.

(c) Chemistry - effect of zero gravity and reduced pressure on exothermic chemical reactions.

(d) Bioscience - investigation of healing process under zero gravity conditions.

(e) Bioscience - effect of zero gravity on plant growth.

The space vehicle would consist of a Saturn IB launch vehicle, an extended CSM, and a LEM-Lab with ascent and descent stages. The experiments carried are summarized in Table 3 (omitted). The spacecraft for this mission is shown in Figures 11 and 12. A typical Bioscience/Physical Science Laboratory mission would be in an orbit of 200 NM altitude and 28.5° inclination. The duration might be 45 days with a crew of three.

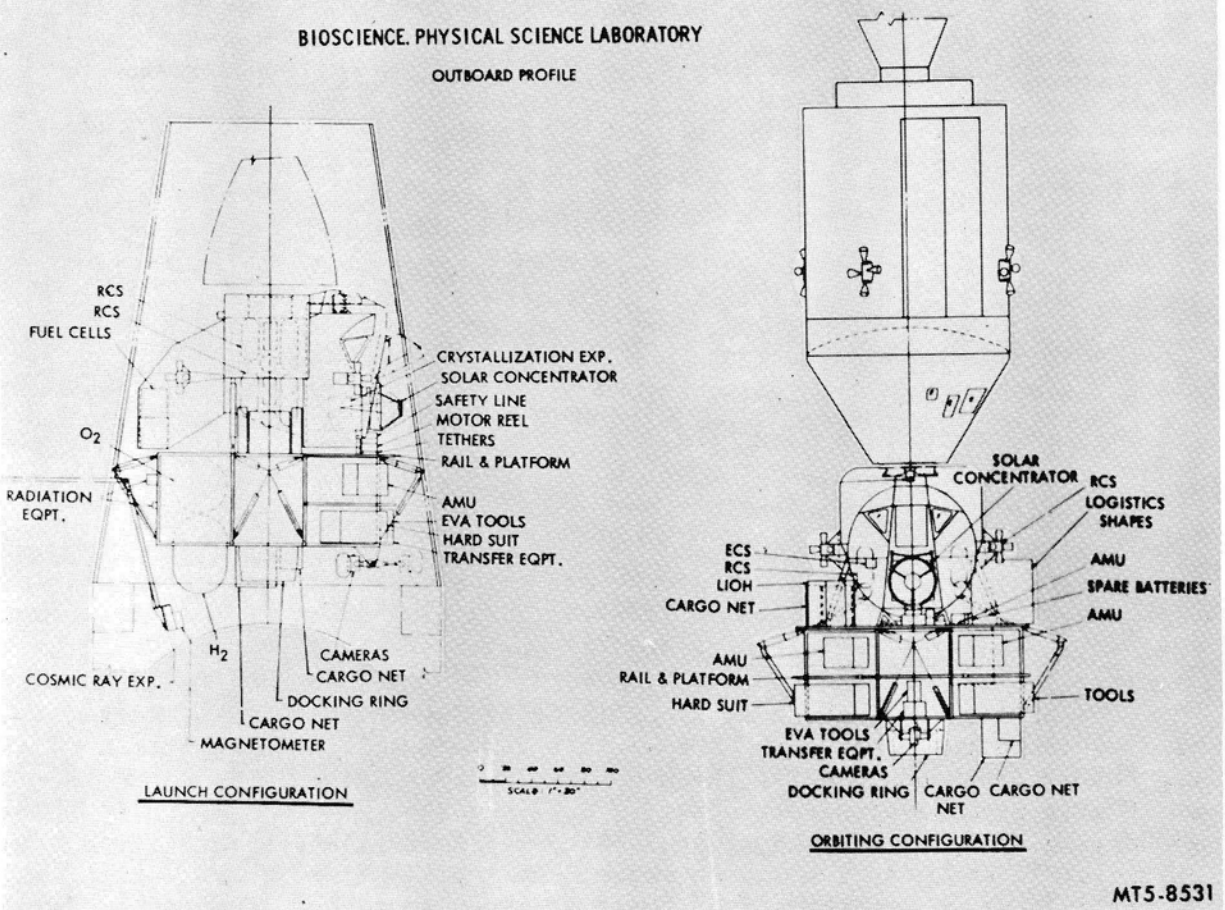


Fig. 11

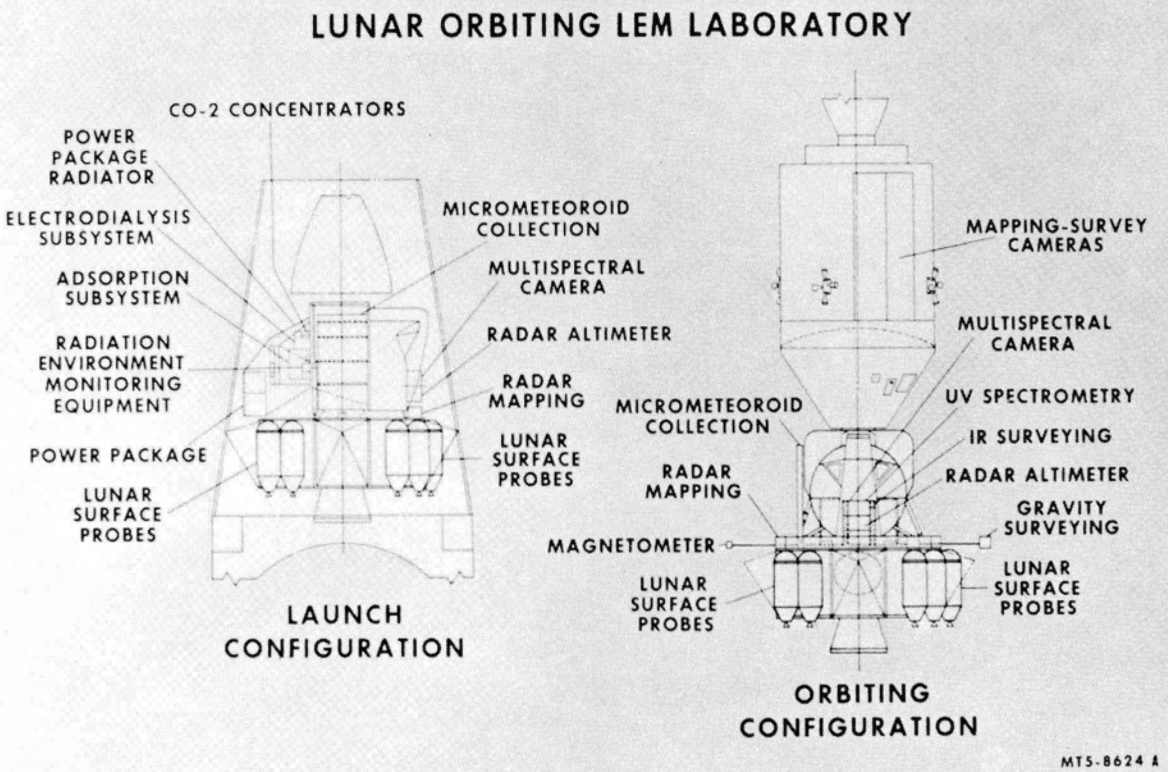


Fig. 12

Earth-Oriented Applications Missions (Remote-Sensing)

The objective of these missions is the observation, by remote sensors, of features both on and above the Earth's surface and the utilization of the information obtained for the benefit of men on Earth. Among the areas which give promise of direct benefits are meteorology, oceanography, geology, geography, hydrology, agriculture, forestry, and upper atmospheric physics. In many cases a common experimental package can serve a variety of disciplines. The emphasis of these missions is on both the acquisition of scientific knowledge and the derivation of practical benefits to mankind.

Space Operations/Technology Missions

The objectives of this class of missions are, first of all, to demonstrate man's ability to perform useful tasks in space, and to take steps to improve his capabilities. Secondly, experiments on these missions would be designed to make the spacecraft and its subsystems more compatible with extended periods of flight. The development of advanced subsystems is a necessary precursor to more extensive operations in space.

Space operations include the general areas of astronaut and spacecraft maneuvering and the performance of functional tasks such as:

(a) extravehicular mobility with a maneuvering unit;
(b) rendezvous with other satellites;
(c) maintenance of onboard and extravehicular equipment;
(d) evaluation of docking and cargo transfer techniques for rendezvous missions;
(e) erection of structures in space.

Technological experiments are aimed toward evaluation and improvement of spacecraft sybsystems and materials such as:

(a) environmental control systems;
(b) fire and blast protection in the spacecraft atmosphere;
(c) long-term exposure effects on spacecraft materials;
(d) development testing of advanced subsystems.

Lunar Missions

The major objective of these missions is the exploration of the Moon in order to illuminate scientific questions concerning its origin, evolution, and inherent properties as well as to investigate its relationship to other bodies in the solar system. In addition, a gradual buildup of technology is sought to provide for orderly extension of space exploration activities during follow-on programs.

Large area surveys from lunar orbit will have great utility in supplementing the extended lunar surfact missions. By interleaving orbital missions and lunar surface missions, it will be possible to correlate both types of data to enable proper planning of each succeeding mission.

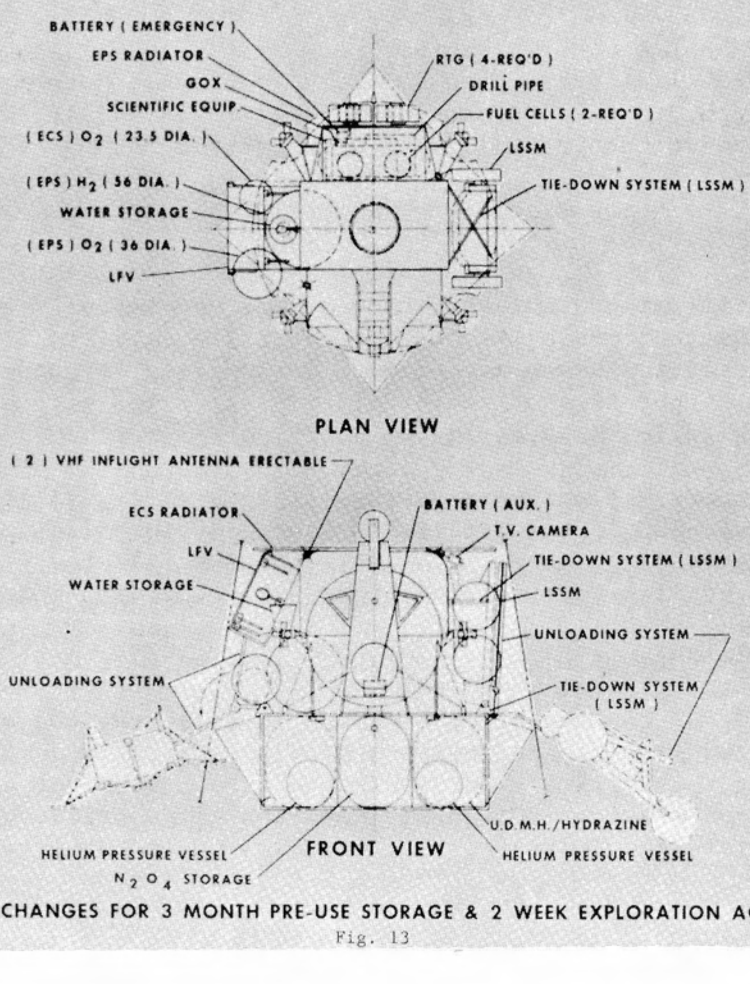
Lunar Orbital Missions

The objective of lunar orbital missions is to survey the Moon, including potential sites for extended surface missions, as well as sites which offer interesting possibilities for surface checks but do not appear worthy of a manned surface mission. Obviously any such large area coverage would serve to extrapolate knowledge from surface missions to other similar areas.

The desired information could be obtained through the use of remote sensors (cameras, radar, etc.) and orbit-to-surface probes, such as Surveyor derivatives.

A typical orbital survey payload would consist of remote sensors ranging through the electromagnetic spectrum from VHF toX-ray, including radar and passive microwave, infrared, the visible spectrum, and ultraviolet. The objectives would pertain to the surface electrical properties, thermal structure, elemental composition, mineralogy, and geology of the Moon. The payload could include from two to six probes, designed to ascertain lunar environment and surface composition.

As presently conceived, the lunar orbit survey missions would be performed using a LEM-Laboratory module as shown in Figure 13.


LEM SHELTER

CHANGES FOR 3 MONTH PRE-USE STORAGE & 2 WEEK EXPLORATION ACTIVITY.

Fig. 13

Lunar Surface Missions

The lunar surface missions are viewed as a logical extension of the basic Apollo mission. The objective of these missions is observation and testing in the vicinity of the landing site and the return of lunar material to the Earth for analysis. The information obtained from such missions may hold the key to many theories on not only the origin of the Moon but also on the whole question of the origin of the Earth and the solar system.

The surface missions are intended to provide a significant increase in scientific return from the Moon by:

(1) Increasing the surface stay time
(2) Increasing the scientific instrumentation
(3) Increasing astronaut mobility

An extended Apollo lunar surface mission, as presently conceived, consists of a lunar flight to deliver an unmanned LEM-Shelter (Figure 14)

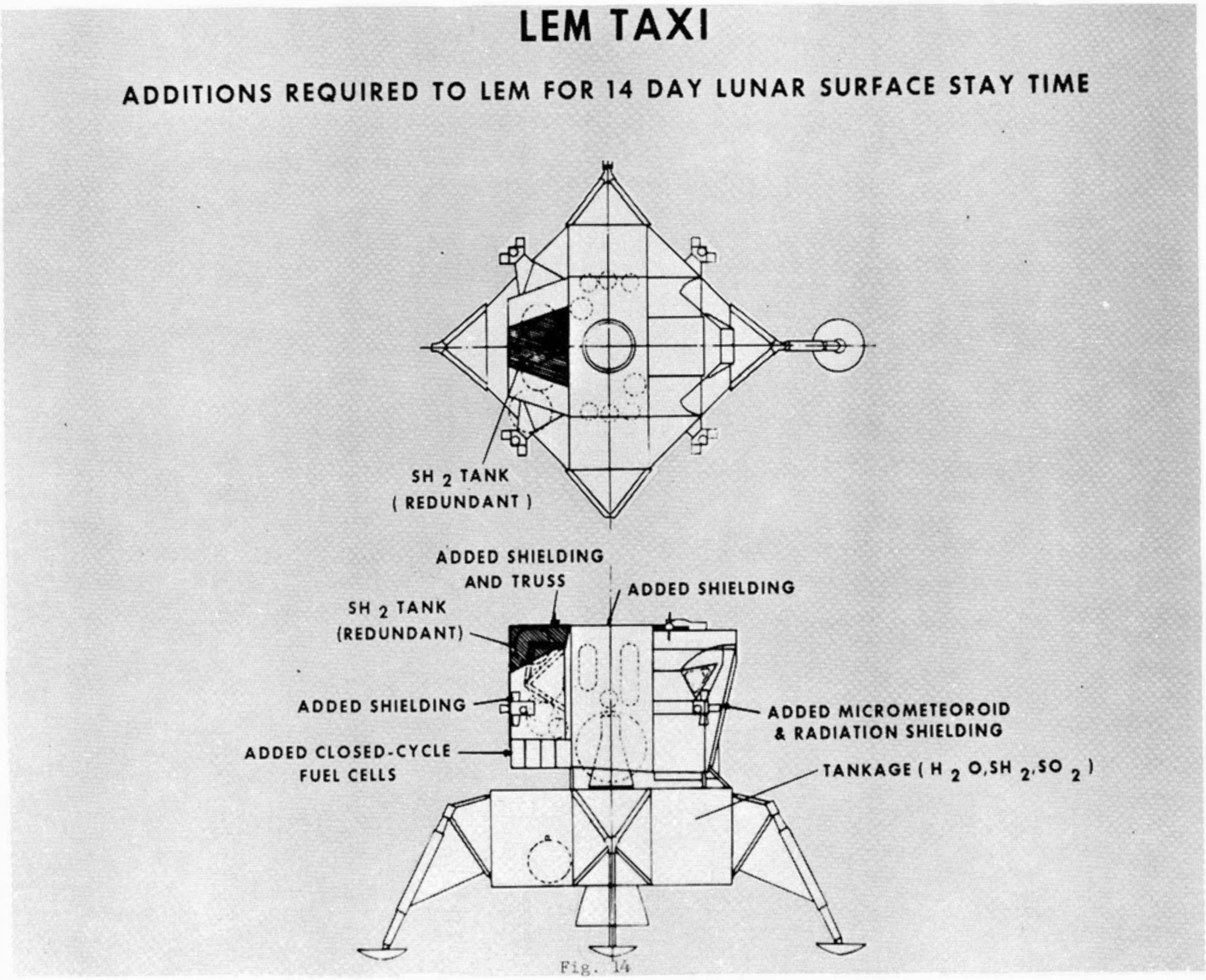
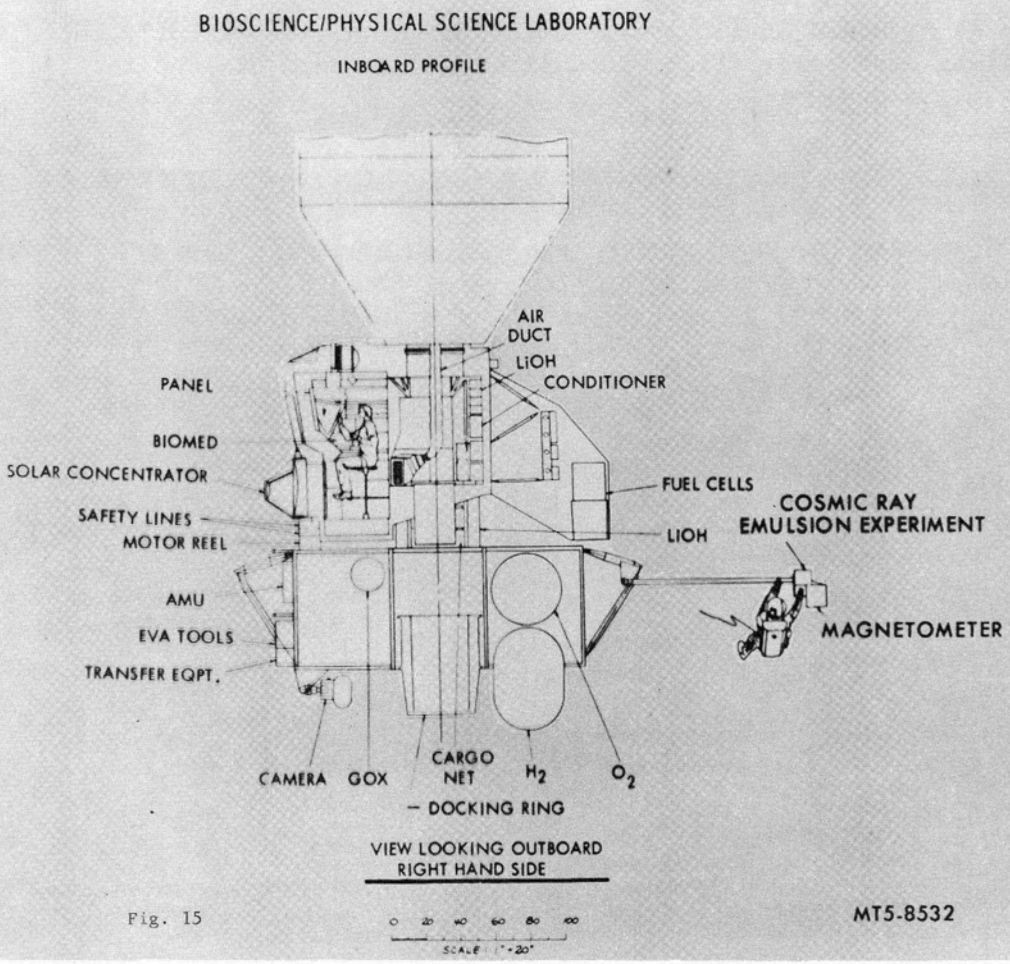


Fig. 14

to the lunar surface, in conjunction with another flight with a LEM-Taxi (Figure 15) to execute a manned lunar landing and subsequent surface operations. Such a mission would permit the astronauts to work on the Moon for about two weeks as compared with approximately one day for Apollo. Their work could also become more efficient through the inclusion in the payload of a mobility aid such as a small roving vehicle or a rocket-powered flying vehicle.


BIOSCIENCE/PHYSICAL SCIENCE LABORATORY

INBOARD PROFILE

VIEW LOOKING OUTBOARD RIGHT HAND SIDE

Fig. 15

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During the lunar stay, the crew would be able to conduct geological and geophysical experiments, survey nearby areas, sample the lunar material with a core drill, and set up an unmanned emplaced scientific station which will remain to operate for long periods of time.

The LEM-Shelter serves both as living quarters for the crew and as a laboratory where preliminary sample analyses, preparation and packing can be done. Several hours per day could be spent monitoring data gathered by the emplaced scientific station. This station would require one or two days to set up and would then operate unattended for perhaps a year. Examples of possible instruments for the emplaced scientific station are:

Gravimeters
Seismometers
Mass Spectrometer
Magnetometer
Radiation Detectors
Solid Particle Detectors
Television
Bore-Hole Probes

The roving vehicle envisaged for the extended lunar mission should be able to carry an astronaut in his space suit throughout an immediate area of approximately six miles in radius and also carry some scientific equipment.

It appears that a great deal of time can be spent by the astronauts in carrying out extensive geological and geophysical surveys over relatively small areas. The information can then be extrapolated to larger areas through the use of orbital observations.

Concluding Remarks

The broad objectives of the Saturn/Apollo application missions, Earth-orbital and lunar, are:

(1) Evaluate and extend man's capabilities to operate in space effectively as an astronaut and as a scientist.

(2) Conduct observations of the Earth, extra-terrestrial phenomena, and experimanets dependent on the space environment.

(3) Qualify systems and crews for subsequent long-duration space missions.

(4) To explore, map and survey the Moon.

Throughout these extended Apollo missions, the primary emphasis will be on science and applications experiments.

The foundation for any long-range and broad national space program is a strong manned Earth-orbital program. For example, the approach to future manned planetary missions will depend not only on what is learned from unmanned missions such as Mariner and Voyager, but also what we learn in Earth orbit about the effects on crew members of long-term confinement and reduced and/or intermittent artificial-gravity fields, as well as on the Earth-orbital qualification of extended-duration life support and power systems.

Man's greatest contributions in space will come when he can bring his intelligence to bear on the spot. He is needed as explorer, scientist, and creative man of judgment, as well as sensor, filter, data processor, pattern recognizor, and manipulator. It is my feeling that we need greatly to increase the exposure of man's mind to the capabilities -- and, especially, the surprises -- of the space environment in order to enable man to understand what is possible and what is not possible; to develop the equipment and skills for carrying out a variety of missions and to do that as expeditiously as possible so that we can make the most of our present achievements.

The application of Apollo and Saturn equipment provides the means, based on launch vehicles and spacecraft now under development, to accomplish this prolonged exposure and experience of man in the space environment as well as the early exploration of the Moon. And it is this experience with manned space operations which will, in turn, enable us to define the next significant steps that we will want to take in space.

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