Direct broadcast FM satellites, illustrated in Figure 38, can be placed in synchronous orbit to develop and demonstrate the techniques of broadcasting directly to home receivers from satellites in space. Direct broadcast satellites would be useful for bringing radio to remote areas where ground broadcast stations are not available, and would also have other potential usefulness for furthering cooperation with other nations.

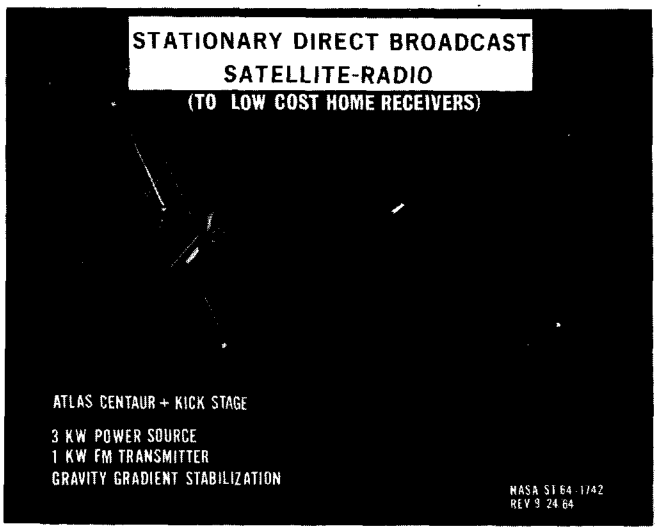


Fig. 38

As presently conceived, such a satellite would be placed in orbit by an Atlas Centaur, with a 7,000-pound high energy stage, or possibly by a Saturn IB/Centaur. It would transmit about one kilowatt of FM power. It will require the development of a stabilization system accurate to plus or minus 1 or 2 degrees and a 3-kilowatt power supply, which could be achieved by the use of radioisotopes.

Also under serious consideration is the development of a combination communication-navigation satellite as illustrated in Figure 39. This satellite would be capable of determining the location of ships and airplanes with high accuracy and furnishing this information to both the vehicles and to ground control stations. It is anticipated that the development of supersonic transport airplanes will magnify the problems of aircraft traffic control. Communication-navigation satellites could be instrumental in systems to meet this problem. The more accurate positioning of ships at sea that could be realized from such a satellite would result in savings in operating costs, and, in the event of a disaster, could materially enhance the rescue operations.

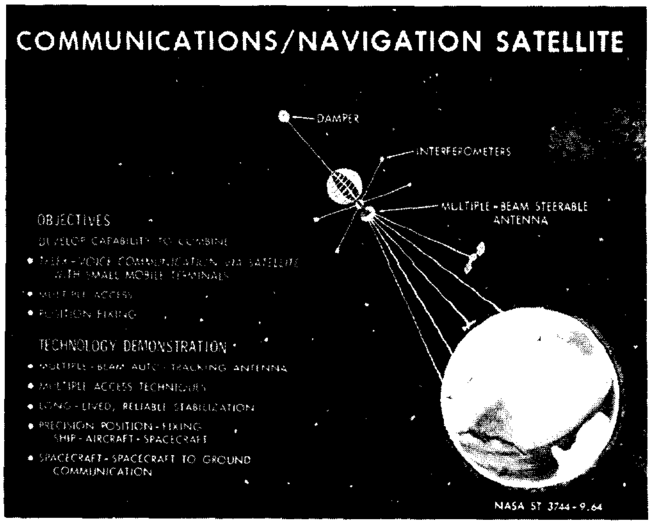


Fig. 39

In the Nimbus meteorological satellite series, NASA will continue to develop meteorological satellite technology, concentrating in the areas of improved infra-red and TV sensors, spectrometers, and interferometers. Also to be tested in further Nimbus flights are various components and techniques that may be used in future automated space data-collecting systems. Such systems would collect meteorological and other information from sensing devices such as buoys at sea, meteorological ground stations, or perhaps constant-altitude weather balloons.

The developments in the Nimbus program will contribute to our capability to identify and track weather fronts and storms from hour to hour and from day to day. Also, it will provide some of the quantitative data for use in electronic computing machines for predicting the weather over longer periods of time. Finally, as a meteorological observatory, Nimbus will provide special observation to improve our understanding of the composition of our atmosphere, its vertical components, and its behavior.

Unmanned Exploration

In the area of unmanned space exploration, many current programs will be continued and, in some cases, extended. In the Pioneer program, spacecraft such as that shown in Figure 40 would be launched both toward and away from the Sun. These aircraft, weighing approximately 140 pounds, will be placed on a trajectory such that approximately 6 months after launch they will be 50 million miles from the Earth, and, depending upon the direction launched, either 0.8 or 1.2 astronomical units (AU) from the Sun. The spacecraft will carry instrumentation to investigate such things as magnetic fields and the temperature and velocity of the solar wind in the interplanetary medium. Also of interest would be the distribution in space of the solar protons emitted from solar flares and the micrometeoroid distribution in the region of the Earth's orbit about the Sun.

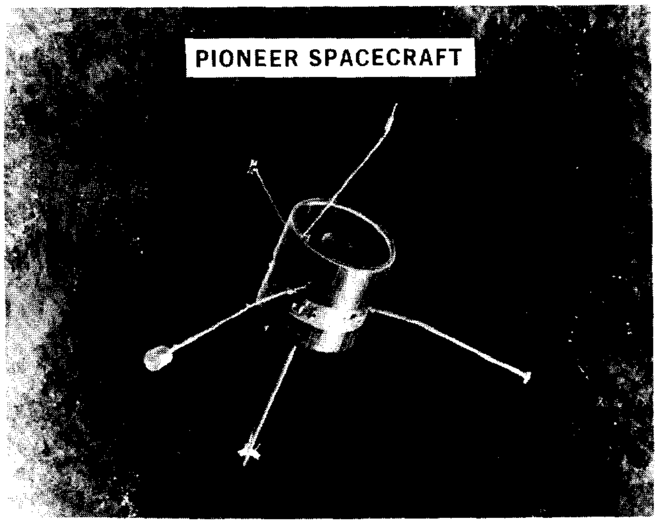


Fig. 40

Initially, the Pioneer spacecraft will be launched by an improved thrust-augmented Thor-Delta booster and will, to a great extent, draw upon existing technology and communication facilities. Present plans also call for Pioneers to be flown during the period of maximum solar activity in 1968-72. During this period, the spacecraft will be launched by Atlas boosters with solid fuel upper stages to penetrate to within 0.4 AU of the Sun.

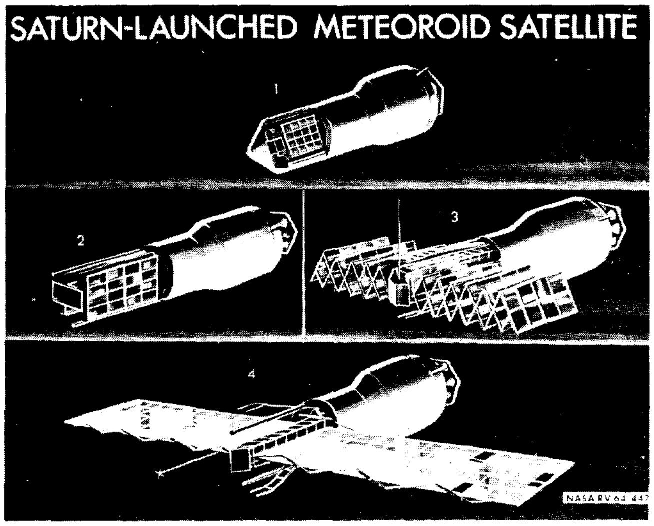
Under consideration for later periods in interplanetary investigation are Advanced Pioneer spacecraft. These spacecraft would weigh between 400 and 750 pounds and would use a 7,000-pound thrust high energy stage with the Saturn IB/Centaur. These advanced spacecraft would be placed in trajectories which might reach as close to the Sun as 0.2 AU or as far away as 8.5 AU. They would be designed for a lifetime of several years. Instrumentation would be similar to that carried by the Pioneer. The probes going away from the Sun would pass through the asteroid belt in the region from 2 to 3 AU, and it would be of use to study this area extensively with micrometeoroid detectors. The galactic cosmic ray flux could be determined for the first time over large distances in the solar system. Present theories predict that the solar wind excludes large numbers of galactic cosmic rays from the solar system, thereby giving an erroneous and low estimate of the true flux of cosmic rays in the galaxy. If this theory is verified, it will require significant changes in astrophysical concepts. Among the technological advances that would be required for these missions are improvements in thermal control and the development of radioisotope power supplied. The large 210 foot antennas being considered for the deep space communication network would be required for the more distant missions.

Another exploratory mission now being considered is an extension of the Pegasus micrometeoroid detection satellite shown in Figure 41. This 3,000-pound spacecraft has been designed to be placed in Earth orbit by the Saturn 1, and will be launched early in 1965. With its "wings" extended (96 feet), it exposes an area of 2,000 square feet designed to detect and count micrometeoroid penetrations. An extension of this program now under consideration would use a Saturn IB/Centaur to send a Pegasus spacecraft to the vicinity of the Moon to determine more precisely the micrometeoroid density in cislunar space.

Future unmanned space missions will also include advanced observatories for more detailed study of the Sun. An understanding of the Sun, its behavior, and of the solar particles emitted from it is important to the study of many phenomena of the Earth. The Earth's weather is to a great extent determined by the behavior of the Sun, which is, in turn, quite variable. Figure 42 shows photographs of the Sun at the two extremes of its activity cycle.

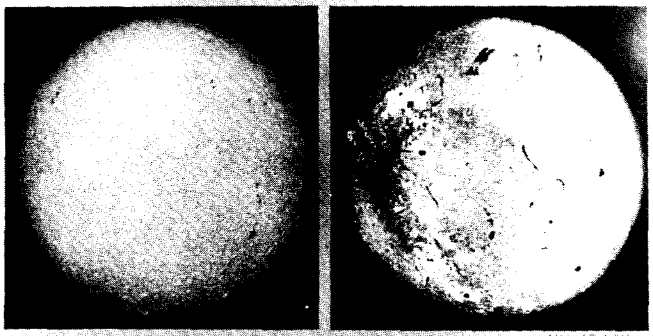
The first Orbiting Solar Observatory (OSO 1) was launched in 1962, the second in February 1965. The Advanced Orbiting Solar Observatory (AOSO), shown in Figure 43, will make improved measurements of various solar phenomena during the next solar maximum. The AOSO will weigh about 1,200 pounds, carry about 250 pounds of instruments, and provide significantly improved pointing accuracy. It will also carry larger and more complex instruments to take advantage of the increased pointing accuracy.

SATURN-LAUNCHED METEOROID SATELLITE



NASA RV 64 447

Fig. 41

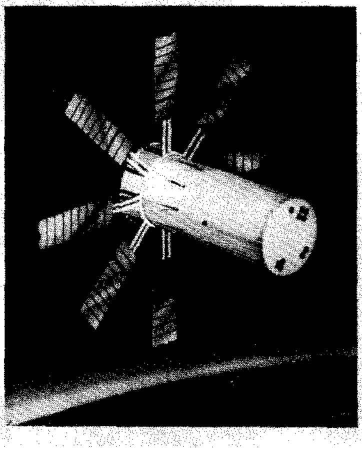


NASA SG64-22

TWO EXTREMES OF SOLAR ACTIVITY

Fig. 42

ADVANCED ORBITING SOLAR OBSERVATORY



GROSS WEIGHT-1200 LBS.
INSTRUMENT WEIGHT-250 LBS.
INVESTIGATIONS-4 TO 6 POINTED
POWER-680 WATTS
STABILIZATION-ACTIVE 3 AXIS
DESIGN LIFE-ONE YEAR
LAUNCH VEHICLE-TAT/AGENA
ORBIT-CIRCULAR 345 MILES
PLAN-FIRST FLIGHT
SOLAR MAXIMUM

NASA SG 65-293
2-8-65

Fig. 43

Shown in Figure 44 is the improvement in resolution that can be obtained by the Advanced Orbiting Solar Observatory over the present capability. As can be seen, resolution will be increased from 1/30 of the solar disk to 1/360 of the solar disk.

One of the most challenging goals of space exploration is the search for extra-terrestrial life. Many scientists think that the planet Mars offers the best possibility of the planets in the solar system, other than the Earth, to support some forms of life.

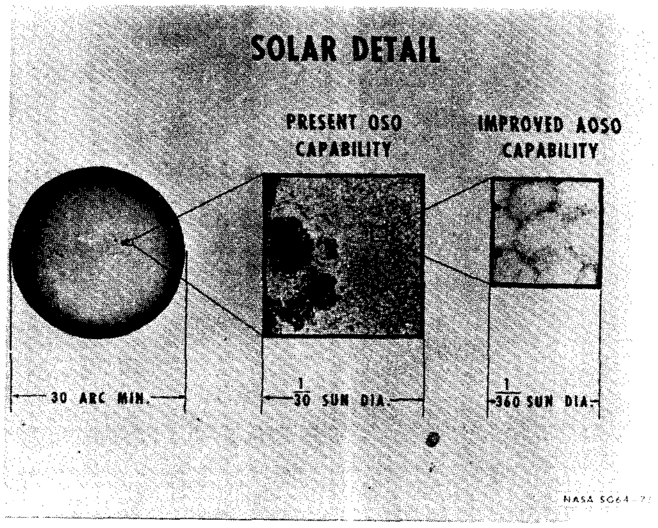


Fig. 44

Planetary exploration will furnish new data on the origin, original composition and evolution of the solar system and will perhaps lead to a better understanding of the origin of the universe.

The problems of planetary flight are substantially more complex than those of Earth orbital or lunar operations. Minimum energy launch opportunities to Mars occur only every 25 to 26 months and the energy required during these opportunities varies with a period of about 15 years.

As can be seen from Figure 45, minimum energy opportunities occur in 1964, 1966, 1969 and 1971 and the required energy increases markedly for the 1973 and 1975 opportunities. Ideal Mars probe velocities corresponding to the minimum energy opportunities are in the order of 42,000 feet per second, as compared with 26,000 feet per second required to attain a 100 mile earth orbit.

To perform a scientifically useful series of missions to Mars will require both orbiting and landing capabilities with a minimum 3-to 6-month spacecraft lifetime at the planet. The lander scientific payload capacity should carry an additional 200 to 300 pounds of instrumentation.

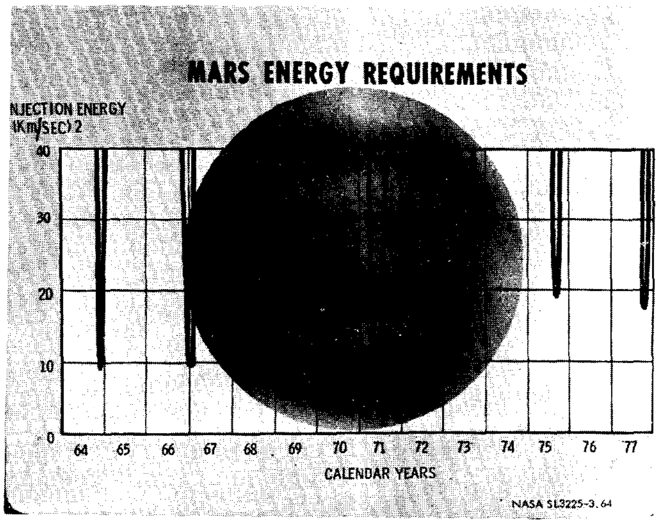


Fig. 45

NASA is now initiating the development of a planetary exploration spacecraft (Voyager) having these capabilities. A basic consideration is the adaptability of the spacecraft to the changing requirements of several Mars opportunities, and its capability for growing with technological development, without the need for a completely new spacecraft design.

The Voyager spacecraft concept shown in Figure 46 will weigh up to 10,000 pounds, up to 5,000 pounds of which will be a soft landing capsule (shown at the top center of the figure), and about 2,000 pounds will be allocated to the orbiting spacecraft. The remainder of the weight will be used in retro-propulsion systems for the landing capsule and for the orbiter.

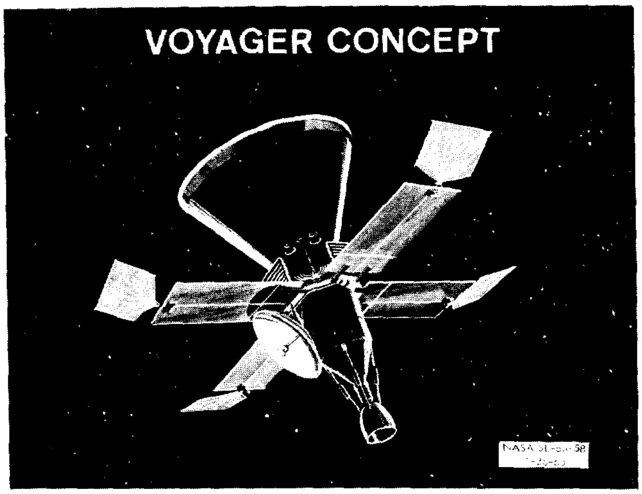


Fig. 46

Orbiter instrumentation will include equipment for continuous planetary surface measurements, measurements of atmospheric phenomena such as aurora and day-glow, and measurements of variation in atmospheric composition and thermal structure. The desired data rates from the orbiter are of the order of 3,000 to 4,000 bits per second, which may require a 50-watt transmitter in the spacecraft and 210-foot ground antennas (as compared with the 8-1/3 bits per second to be returned by the Mariner IV).

Figure 47 shows what the lander might look like deployed on the Martian surface. During descent the capsule would make measurements of the state and composition of the Martian atmosphere and would transmit these data to the orbiter for relay to Earth.

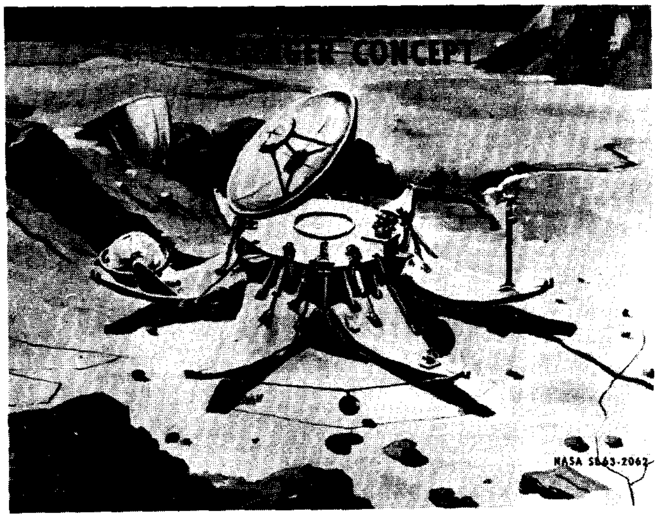


Fig. 47

Many technological advances would be made incident to the development of the Voyager. In addition to the 210-foot antennas on the ground, larger spacecraft antennas and 50-watt transmitters necessary for communications, and improvements in guidance, control and tracking technology and in engine, propellant storage and mechanical operation technology are required to place the spacecraft in orbit about Mars and to land the instrumentation packages at specified locations on the planet's surface. Reliability also must be improved since even minimum planetary exploration will require a failure-free operating lifetime of almost a year. The landing capsule would require a light-weight radioisotope power source capable of producing several hundred watts. Furthermore, if we are to be assured that the Martian surface would not be contaminated by bacteria carried there from the Earth, all parts of the spacecraft or capsule which might enter the atmosphere or land on the planet must be thoroughly sterilized. Lander instrumentation might include experiments utilizing surface photography, microscopy, light scattering, or radioisotope techniques for detecting micro-organisms or other elementary life forms. Geological and geophysical experiments might also be included utilizing such instruments as a seismometer, a gravity meter and a petrological microscope; and instruments for measurements of atmospheric composition and profiles. In later versions, the landing capsule might contain an automated biological laboratory and possibly a small roving vehicle designed to make integrated measurements of the Martian biology and ecology.

A careful study of planetary mission requirements has shown that the vehicle most effective for accelerating the Voyager-type spacecraft with the optimum weight and/or volume to the 42,000-foot-per-second velocities required to reach Mars would be a Saturn IB/Centaur combination. Furthermore, the Saturn IB/Centaur would provide in the National Launch Vehicle program a flexible, general-purpose vehicle for planetary and deep space exploration.

Preliminary studies indicate that this Voyager-Saturn IB/Centaur planetary exploration capability could be available in time to take advantage of the 1971 Mars opportunity. It is possible that an initial version of this spacecraft without the soft landing capsule can be developed in time to take advantage of the 1969 Mars opportunity for fly-by or orbital test missions.

Manned Operations

NASA planning for future manned missions seeks to make most effective use of the launch vehicle and spacecraft capability being developed in the Apollo program. It now appears that elements of this capability could be available as early as 1968. The total Apollo program will build up, by 1969, to a capability to launch six Saturn IB vehicles and six Saturn V vehicles annually. The program can also provide up to eight Apollo spacecraft annually for a broad spectrum of space flight missions.

Extended use of the Apollo-LEM system requires an increase in flight duration capability beyond the 2 weeks presently programmed. Initially, the Earth-orbital stay time of the Apollo spacecraft could be extended to one month, and later possibly to 2 or 3 months.

On board power for the extension to one month can be provided by increasing the number of fuel cell banks from three to five to improve the reliability and lifetime. In addition, a space restart capability for the fuel cells will be developed. The weight of the cells and the hydrogen and oxygen reactants will increase from about 2,500 pounds to about 5,000 pounds. These changes will allow up to 1,500 watts to be drawn intermittently for experimental programs.

The increase in the Apollo-LEM system life support capability from 2 weeks to one month can be accomplished by retaining a single gas (pure oxygen) system. Additional equipment such as a debris trap and a catalytic burner will be provided for more positive detection and control of contamination in the cabin atmosphere. Some higher density nutrients will be added to reduce food storage volume requirements. Additional lithium hydroxide canisters for carbon dioxide removal will be installed.

The net weight added to the Command and Service Module to provide the one-month capability, taking into account the added weight of the power and life support systems and the reduction in weight due to removal of fuel and fuel tanks, will be about 2,000 pounds.

For a 90-day capability, the changes to the Apollo-LEM system will be more substantial and will include items such as the following:

a. Change from a single gas life support system (pure oxygen) to a dual gas system (oxygen and an inert gas, probably nitrogen or helium);

b. Use of a molecular sieve for recovery of oxygen from carbon dioxide;

c. Improved cryogenic storage for hydrogen and oxygen;

d. Provision of an alternate electrical power source such as solar cells or a radioisotope power supply;

e. Provision of additional food storage;

f. Provision of added waste management capacity;

g. Provision of a longer life attitude control system; and

h. Improvement in the Command and Service Module rocket engine to provide a reliable restart capability after a 90-day storage in space.

The Apollo-LEM system has a large and versatile capability for a variety of missions. The Command Module provides about 190 cubic feet of usable working space. As indicated by the shaded area in Figure 48, 250 cubic feet of unpressurized volume is also available within the basic Service Module for payloads and/or expendables. This volume is sufficient for flight durations up to one month. In addition, it is possible (though inefficient from the weight standpoint) to extend the duration in Earth orbit up to 3 months by removing the propellant tanks from two additional bays and adding more fuel cells and expendables in that space as shown in outline form in Figure 48.

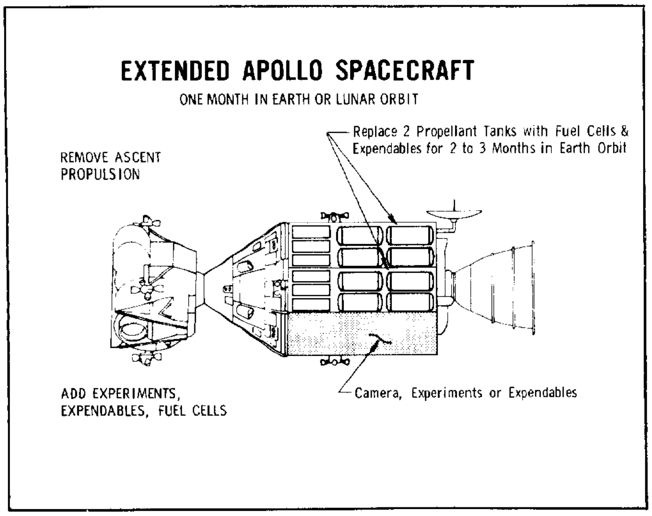


Fig. 48

If additional pressurized volume is required, the ascent stage of the Lunar Excursion Module (LEM) can be used. By removing the LEM ascent engine, its propellant, the LEM life support equipment, and other lunar landing mission equipment, the total available volume can be more than doubled. However, there will be other missions, such as rendezvous and inspection, where the LEM descent engine will be retained so that the space maneuverability of the basic LEM can be used.

Some of the possible missions which might be carried out using the extended Apollo capabilities are illustrated on Figure 49. A Saturn IB launch vehicle will provide sufficient thrust for placing one of these spacecraft in a low inclination orbit below the Van Allen belts where the basic problems of keeping men in space for extended periods can be studied, rendezvous and resupply problems can be worked out, and scientific experiments can be conducted.

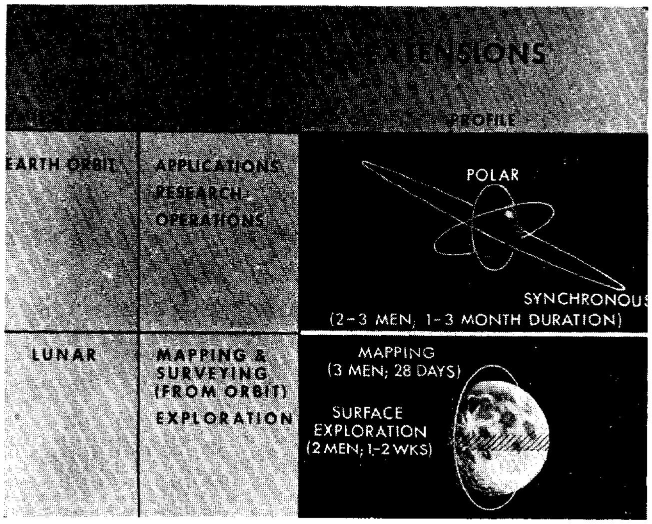


Fig. 49

A Saturn V launch vehicle might be used to place one of these spacecraft into higher inclination or polar orbits for operations which require frequent observation of the entire surface of the Earth. A Saturn V could place one of these spacecraft into a synchronous orbit to carry out experiments which involve manned observations over a given portion of the Earth or which use man to assist in the operation of various experimental systems.

Mapping and surveying of the lunar surface from orbit could be accomplished by injecting the spacecraft into a lunar polar orbit and extending the orbital mission duration to about 28 days. This would permit the entire lunar surface to pass beneath the spacecraft under good lighting conditions.

Figure 50 shows several possibilities for extension of the capabilities of the basic Apollo-LEM system when used with the Saturn IB and Saturn V launch vehicles. It illustrates possible trade-offs between instrument payload and maneuverability for several launch vehicle-spacecraft configurations in various orbits.

EXTENDED APOLLO MISSION CAPABILITIES

MISSION	CONFIGURATION	ORBIT N.M INCL	DURATION (DAYS)	PAYLOAD (LBS	ΔV fps	EQUIVALENT PLANE CHANGE (deg
EARTH ORBIT	SAT IB/XCSM/LEM AS	200/30°	30	5,000 0	0 2,000	– 4
EARTH ORBIT	SAT V/XCSM/LEM ASP	200/30° INITIAL	30	210,000 0	0 26,000	– 60
			90	200,000	0	–
EARTH ORBIT	SAT V/XCSM/LEM AS	200/POLAR	30	17,500 0	0 4,000	– 9
EARTH ORBIT	SAT V/XCSM/LEM AS	200/POLAR	60	12,500 2,000	0 2,000	– 4
EARTH ORBIT	SAT V/XCSM/LEM AS	SYNCHR./0°	30	9,500 0	0 1,500	– 9
EARTH ORBIT	SAT V/XCSM/LEM AS	SYNCHR./28°	60	10,000	–	–
LUNAR MAPPING	SAT V/XCSM/LEM ASP	80°/POLAR	28	9,500	–	–
LUNAR SURFACE EXPLORATION	SAT V/XCSM/LEM (DUAL LAUNCH	LUNAR SURFACE	14	2,500	–	–

NOTES: XCSM - APOLLO COMMAND AND SERVICE MODULE WITH ADDITIONAL SUBSYSTEMS AND EXPENDABLES
LEM AS - LEM ASCENT STAGE WITHOUT SUBSYSTEMS, DEPENDENT ON XCMS
LEM ASP - LEM AS PLUS LEM DESCENT STAGE PROPULSION

Fig. 50

For example, the first line indicates the capability of a Saturn IB to orbit an Apollo Command and Service Module and LEM modified for a stay time of 30 days. With such a configuration, a choice would exist between carrying 5,000 pounds of payload with no fuel available for maneuvering, or no payload with fuel sufficient for a total velocity change of 2,000 feet per second which might be used for a 4-degree change in orbital plane. The payload and velocity increment combination shown represent end-points. Various combinations of payload and fuel between these limits are also possible. Although not indicated in the figure, this configuration will support three men for 30 days. The lifetime could be extended beyond the 30 days by changing to more efficient subsystems, particularly in the power and life support area. With a two-man crew, the spacecraft lifetime might be extended up to 3 months.

The Saturn V provides a much greater mission flexibility. Line 2 of Figure 50, for example, describes a Saturn V launch configuration in which either a very large payload or fuel for a very large velocity increment could be placed in a low-altitude, low-inclination (about 30 degrees) orbit. The spacecraft configuration consists of an extended Command and Service Module plus a modified LEM ascent stage together with the LEM descent stage propulsion. If all propulsion systems are then used to capacity, this extended Apollo spacecraft would have a capability for a total velocity increment of about 26,000 feet per second which is equivalent to a 60-degree low-altitude orbital plane change. In this configuration the S-IVB stage, Service Module, and LEM descent stage propulsion would all be utilized for plane changes.

Line 3 of Figure 50 describes the capabilities of a spacecraft configuration similar to the basic configuration shown in the first line when launched by a Saturn V. For a 30-day polar orbit mission, 17,500 pounds of payload or fuel can be carried. This launch could be accomplished from the Cape Kennedy launch sites and still remain within the range-safety limits. In this mission, Service Module propulsion would be used during part of the polar orbit injection maneuver.

In the fourth line, the configuration and mission are similar to those previously described, except that a 60-day mission duration is achieved in polar orbit. Here again there is the choice between the maximum mission equipment payload of 12,500 pounds or a 2,000-feet-per-second maneuvering capacity. It may be noted that on this 2-month polar orbit mission the available volume for propellant tankage is sufficient only to provide a 2,000-feet-per-second velocity increment, which does not use up all of the available payload.

The fifth line shows a mission capability in an equatorial synchronous orbit in which the spacecraft would appear to be stationary over a point above the equator. Line 6 describes a similar configuration in a 60-day mission, but with the synchronous orbit achieved at a 28-degree inclination so that an equipment payload of 10,000 pounds can be carried. The two missions of lines 5 and 6 each require Service Module propulsion to achieve orbital injection.

As shown in the seventh line, the extended Apollo spacecraft, equipped with the LEM and its descent propulsion stage, is also capable of carrying about 9,500 pounds of lunar survey equipment in a lunar polar orbit. In this configuration, the added LEM descent propulsion is used for a portion of the lunar orbit injection maneuver in order to leave additional propellant in the Service Module. This additional Service Module propellant is necessary in order to provide a continuous capability to abort from the lunar polar orbit during any of the 28 days of operations.

The bottom line of Figure 50 describes how two Saturn V launches may be used to provide a 14-day lunar surface exploration capability. In the first launch, an unmanned LEM, modified to provide shelter and life support for two men for 14 days, is landed on the lunar surface. The astronauts are landed in a second LEM which will remain in a quiescent state while the astronauts live in the shelter. At the end of the 14-day mission, the LEM which landed the astronauts is reactivated to carry them back to the Command and Service Module in lunar orbit for the return to Earth. A discussion of the returns to be derived from such a mission is presented later.

Shown on Figure 51 are the classes of experiments that could be carried out during extended earth orbital missions. The three basic classes are Space Sciences, Earth-Oriented Applications and Support for Space Operations.

Studies of the effects of the space environment on man's circulatory and respiratory systems, metabolism rate, and nerve, muscle and bone tissues are of interest not only because of their necessity for further manned space operations, but also because of the application they might have to the understanding of human physiological processes. Experiments would also determine the effects of prolonged weightlessness and confinement on human behavior and psycho-motor performance.

MANNED EARTH ORBIT EXPERIMENTS

I SPACE SCIENCES
  BIOSCIENCES
  PHYSICAL SCIENCES
  ASTRONOMY/ASTROPHYSICS
II EARTH ORIENTED APPLICATIONS
  ATMOSPHERIC SCIENCE AND TECHNOLOGY
  EARTH RESOURCES SURVEY AND INVENTORY
  COMMUNICATIONS
III SUPPORT FOR SPACE OPERATIONS
  ADVANCED TECHNOLOGY AND SUBSYSTEMS
  OPERATIONS TECHNIQUES/SUBSYSTEMS
  BIOMEDICAL/BEHAVIORAL

Fig. 51

Other biological experiments could be run to determine the effects of zero gravity and radiation upon the growth rate and mutation rate of bacteria. For example, Hela cells might be grown in space to determine whether zero gravity affects animal tissue growth at cellular levels.

An important experiment which might be carried out in an extended Apollo spacecraft would involve a highly instrumented primate. The instrumentation would include deep brain probes and cardiovascular implants, and a variety of metabolism experiments. The primate would also have a separate life support system, so that the effects of various atmospheres on the body functions could be studied. The astronauts would observe the behavior of the primate and, in addition, might conduct various experiments in which the primate would receive injections. Behavioral experiments would be conducted to determine both weightlessness and biorhythm effects.

Extended Apollo missions will provide an opportunity for proving out capabilities for various space operations such as rendezvous or orbit-change maneuvers. Techniques for extra-vehicular activities as may be needed in external repair and maintenance of spacecraft, or in erection of large space structures, such as antennas or solar energy collectors, might also be investigated.

Similarly, many of the problems that will be associated with orbital launch of interplanetary spacecraft can be simulated with the extended Apollo. Countdown and checkout procedures can be exercised, induced perturbations studied, fuel handling and transfer techniques can be tested, and inspection and repair techniques developed.

In addition, the extended Apollo spacecraft could be used as a "truck" to carry complete scientific satellite payloads into space where they could be removed from the Service Module, checked out and adjusted by an astronaut, and left in orbit to transmit data in the conventional manner.

With their astronauts, Apollo extensions will provide special capabilities which the meteorological community can adapt to meteorological experiments designed to further our understanding of the behavior and structure of the Earth's atmospheric envelope. Scientifically significant experiments in the fields of photographic and visual observations, spectrometry, radar, far-infrared sensing, and television are definitely feasible. These meteorological experiments can exploit the spacecraft advantages which permit the in-flight modification of experiments, equipment design simplicity, in-flight testing of experimental concepts, module-to-ground communication, data recoverability, and the observation of infrequent but meteorologically significant phenomena.

Manned spacecraft could also determine the feasibility of carrying out synoptic and multi-sensor mapping of the earth. Polar-orbiting spacecraft would be desirable for these mapping operations since the entire earth could then be viewed in 24 hours. These operations might provide a comprehensive earth resources survey and inventory covering the fields of agriculture, forestry, geology, hydrology, oceanography and geography. Activities in these areas would be developed in close coordination with other government agencies and departments.

In the field of astronomy, preliminary studies are underway to determine the feasibility of adapting the Orbiting Astronomical Observatory to manned operation. These modifications might include the use of film which, in many cases, has great advantages over vidicon tubes or other electronic sensors. Each square centimeter of film contains over 10^9 bits of information--more than can be telemetered to Earth in one hour. Astronauts could also maintain the spacecraft and repair and replace instrument packages. This mission would develop the techniques that might be used in later missions involving space stations and telescopes as large as 100 inches in diameter which might be assembled in space.

In the category of advanced technology and subsystems, small critical spacecraft components or subsystems can be tested in a true space environment before they are committed to use in longer duration missions. For example, some of the key components which might be used for recovering oxygen from carbon dioxide in Earth orbiting space stations, lunar bases, or manned planetary missions involve processes which have not yet been tested in a zero-gravity environment. Such tests can be conducted in a manned spacecraft where the presence of man will provide an ability to observe, adjust, and maintain the test and to make preliminary data analyses.

Many basic questions regarding behavior of liquids, solids (as regards crystal growth, for example), and gases under zero-gravity conditions could be answered by simple tests which can be carried out aboard the spacecraft. Results of such experiments would be of fundamental scientific interest and would also be useful in the design of fuel tanks and fuel pumping systems for use under zero-G conditions.

As noted earlier, another extension of the Apollo system involves providing additional stay time on the lunar surface by utilizing the supply capability of the Lunar Excursion Module.

Among the returns to be derived from extended manned exploration of the Moon, one of the first items to be noted is the acquisition of new knowledge of the origin of the Moon and the additional new knowledge which this would provide relative to the origin and early history of the Earth. For example, answers might be expected to fundamental questions such as whether the Moon was once originally part of the Earth which escaped during the Earth's earlier history, whether it was captured by the Earth after having been formed in some other place in the Universe, or whether it was formed at the same time as the Earth out of the same primordial cosmic dust.

The instruments, equipment, and additional life support elements required for extended exploration would be carried to the lunar surface by an unmanned version of the LEM, illustrated in Figure 52, designed to carry equipment and supplies in place of the astronauts and the ascent propulsion motor and its fuel. This vehicle would be landed under remote control at a suitable location on the Moon's surface, and, after its safe landing, another Apollo vehicle carrying two astronauts would land in the same location. The astronauts would then unpack the equipment carried by the automatic LEM, and proceed to set up instruments and carry out various scientific experiments.

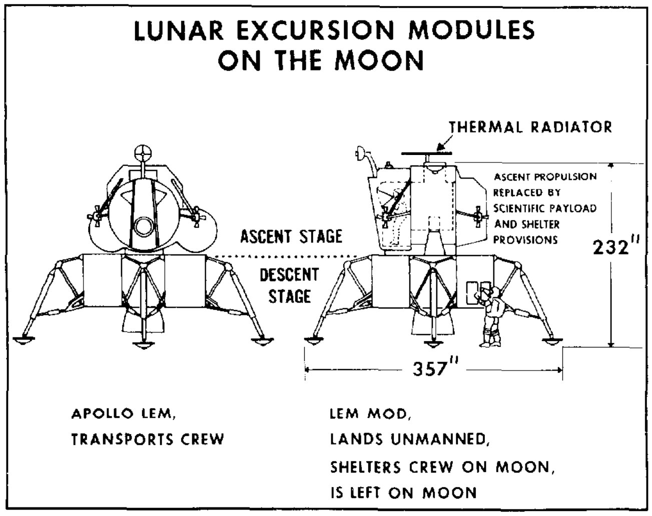


Fig. 52

As presently foreseen, these surface missions could take several forms ranging from those in which the astronauts are limited to the area that they can cover on foot in their spacesuits to later missions in which they might be equipped with a small roving vehicle which could extend their range to several miles.

In addition to shelter and life support equipment, the unmanned LEM can carry as much as 2,500 pounds of equipment and scientific instruments. This equipment might include a lightweight drill which the astronauts could operate while on the lunar surface. This would permit the taking of core samples and the logging of the hole which would be invaluable to both geological, geophysical and biological investigations.

Geologists would be able to determine the existence and composition of stratification layers on the Moon. Biological analysis of these core samples would be useful in determining if life forms presently exist or existed in the past on the Moon. Also, temperature measurements in the bore hole would furnish thermal information on the lunar interior.

In addition to taking core samples which they would return to Earth, the astronauts could place self-contained scientific instrument packages in the vicinity of their landing sites. These packages, which would transmit their data directly to Earth, might include seismic detectors, gravimeters, magnetometers, solar particle radiation detectors, and large-area micrometeoroid detectors.

Experiments to determine the feasibility and the potential benefits that might be accrued by using the Moon as a base for astronomy, both optical and radio, could be conducted on these missions. Very low frequency radio emissions could be received by an antenna on the Moon, a scientific investigation made impossible on Earth by the ionosphere. Additionally, the high (10^{-13}torr) vacuum anticipated in the vicinity of the Moon provides an environment not attainable on Earth in which to conduct experiments.

In later missions the equipment landed might include a small, open, roving vehicle which would permit traverses of several miles. During these traverses, seismic profiles could be recorded by arranging geophones and emplacing explosive charges at selected points, continuous profiles of the gravitational and magnetic fields could be obtained, outcrops exposing the lunar stratigraphy and contacts between geologic units could be visited for close-up inspection and sampling, and continual measurements could be made on the chemical and radioactive properties of the surface.

Launch Vehicles

With respect to the launch vehicles required for the missions to be undertaken in the next few years, a need for mating the Centaur to the Saturn 1B and a requirement for a new 7,000-pound thrust high energy stage have been indicated.

NASA is now developing the Centaur hydrogen-oxygen propulsion stage for use with the Atlas launch vehicle in the Surveyor program. Studies have shown that this Centaur stage is also close to optimum for developing the full payload capability of the Saturn IB for launching planetary payloads. Further, it appears possible that the Centaur can be mated to the Saturn IB without major modifications to either the Centaur or the Saturn IB upper stage.

The Saturn IB/Centaur combination shown in Figure 53 is needed as a general purpose space exploratory vehicle for missions such as the 10,000-pound Voyager spacecraft to Mars, for sending advanced Pioneer spacecraft close to the Sun and out beyond the orbit of the asteroids and for sending the Pegasus micrometeoroid spacecraft to the vicinity of the Moon. It might also be used to place heavy payloads, such as the direct broadcast TV satellite, in synchronous orbit. The present program is developing a capability which would permit two launches from a single launch pad during a Mars or Venus opportunity. This vehicle might also be used for propelling two light-weight spacecraft, such as two advanced Applications Technology Satellites, on a single launch.

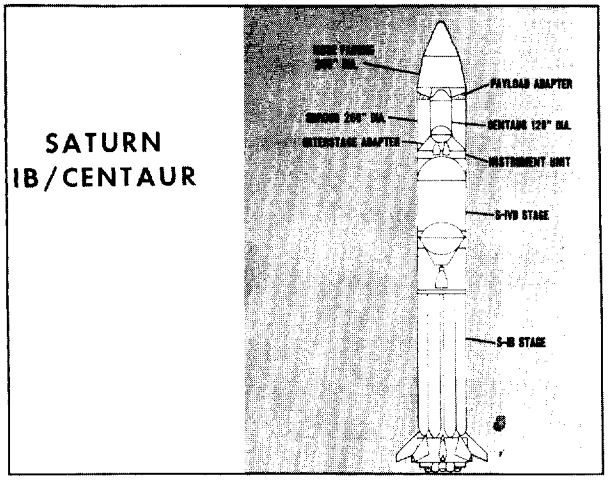


Fig. 53

The 7,000-pound thrust high energy stage will be developed to fit on top of the Centaur and thus could be added to the Atlas/Centaur or the Saturn IB/Centaur. This stage might also be incorporated as the retro-propulsion system to place the Voyager spacecraft into a Martian orbit. When used with the Atlas/Centaur, it could propel heavier science and application satellites, such as the Orbiting Geophysical Observatory or FM Broadcast satellites, into synchronous or stationary orbits, or send lighter spacecraft to within .3 AU of the Sun or out to 4 AU.

Added to the Saturn IB/Centaur, this high energy stage can perform missions designed to reach the more distant planets, escape from the solar system, or explore space near Mercury and the Sun. It will also allow initial exploration of the solar system outside the ecliptic plane.

Technology

Technological advances required for the intermediate missions will be an outgrowth of present efforts. Manned missions for durations of 30 days will require improvements in fuel cells, and, for periods longer than 30 days, will require power sources producing several kilowatts. The Voyager mission to Mars will require a guidance and control system capable of landing a capsule within 250 miles of a pre-selected site on Mars, a communications system capable of transmitting at least 3,000 bits of information per second over the 250 million-mile Earth - Mars conjunction distance, reliability sufficient to insure 3- to 6-month spacecraft lifetime at the planet after a 7-month trip through space to the planet, and sterilization techniques that can insure a probability of less than one chance in 10,000 of contaminating Mars. Life support systems capable of supplying the needs of three men for one to 2 months will be required, as will stabilization systems capable of stabilizing a synchronous altitude satellite within plus or minus 2 degrees and of pointing a satellite such as the Advanced Orbiting Solar Observatory at a spot on the Sun 1/360th of the Sun's diameter.

Research and technology development programs should be planned not only to supply the technology specifically needed by the current and intermediate flight missions, but also to increase the already broad base of fundamental knowledge and understanding. A broad program of this sort makes possible a continuous and accurate assessment of what should be and what can be done in space at any time, and provides the flexibility which is needed to permit major new space flight programs to be undertaken, or existing programs to be redirected, on short notice. Such a program often provides unforeseen, valuable, new methods of solving difficult technical problems.

Thus, for the near future, the research and technology program must include those developments in launch vehicle and spacecraft technology which provide a basis for the selection and accomplishment of the missions to be undertaken in the more distant future. These are discussed in the next section, together with a survey of possible future missions.

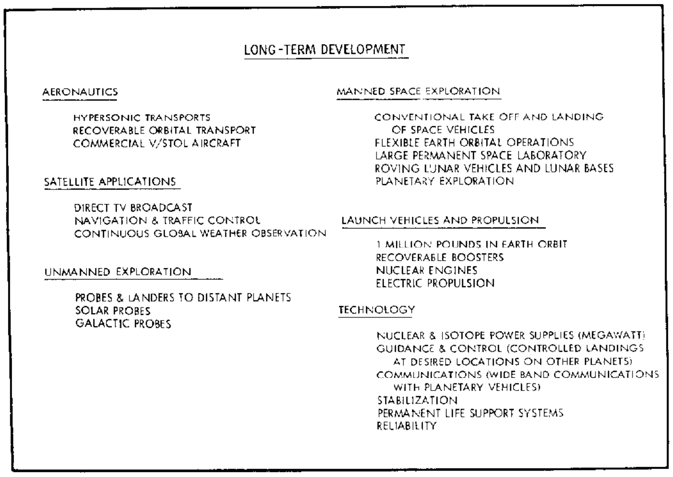
The intermediate missions which might be undertaken within the next several years, as discussed above, are believed to serve a threefold purpose of (1) meeting national objectives in space, (2) effectively using existing capabilities, and (3) providing a solid base for undertaking those longer-range, advanced missions which might be undertaken within the next several decades.

V. LONG-RANGE AERONAUTICAL AND SPACE DEVELOPMENTS

The concluding portion of this discussion will be a review of the advanced developments in aeronautics, satellite applications, manned and unmanned space exploration, and launch vehicles which we believe will provide the foundation for the space program of the more distant future.

Many of the longer-range developments listed in Figure 54 call for extreme advances in technology that cannot now be clearly foreseen. However, the rapid technological advances of recent years, together with steps that are clearly possible, provide confidence that the work can be accomplished.

We further believe that these kinds of advances not only *can* be made, but *will* be made, if not by the United States, then by Soviet Russia, or possibly by some other nation. Further, if vigorous, intelligent, well-planned and well managed programs are pursued, such advances can be made in an orderly progression without crash programs or excessively expensive efforts.



LONG-TERM DEVELOPMENT

AERONAUTICS

- HYPERSONIC TRANSPORTS
- RECOVERABLE ORBITAL TRANSPORT
- COMMERCIAL V/STOL AIRCRAFT

SATELLITE APPLICATIONS

- DIRECT TV BROADCAST
- NAVIGATION & TRAFFIC CONTROL
- CONTINUOUS GLOBAL WEATHER OBSERVATION

UNMANNED EXPLORATION

- PROBES & LANDERS TO DISTANT PLANETS
- SOLAR PROBES
- GALACTIC PROBES

MANNED SPACE EXPLORATION

- CONVENTIONAL TAKE OFF AND LANDING OF SPACE VEHICLES
- FLEXIBLE EARTH ORBITAL OPERATIONS
- LARGE PERMANENT SPACE LABORATORY
- ROVING LUNAR VEHICLES AND LUNAR BASES
- PLANETARY EXPLORATION

LAUNCH VEHICLES AND PROPULSION

- 1 MILLION POUNDS IN EARTH ORBIT
- RECOVERABLE BOOSTERS
- NUCLEAR ENGINES
- ELECTRIC PROPULSION

TECHNOLOGY

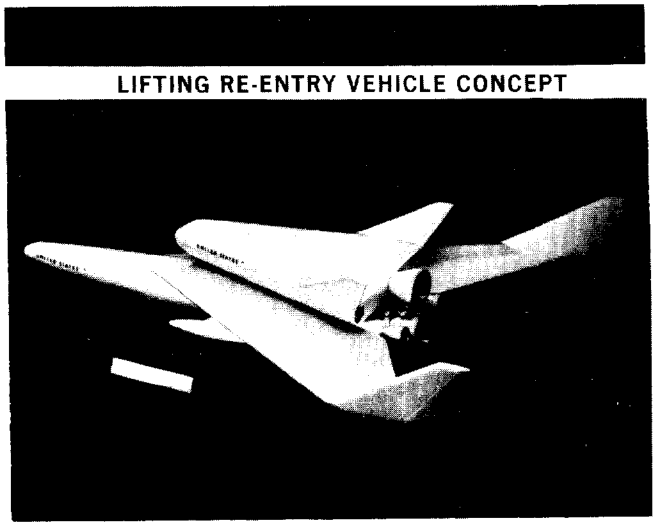
- NUCLEAR & ISOTOPE POWER SUPPLIES (MEGAWATT)
- GUIDANCE & CONTROL (CONTROLLED LANDINGS AT DESIRED LOCATIONS ON OTHER PLANETS)
- COMMUNICATIONS (WIDE BAND COMMUNICATIONS WITH PLANETARY VEHICLES)
- STABILIZATION
- PERMANENT LIFE SUPPORT SYSTEMS
- RELIABILITY

Fig. 54

Aeronautics

In the field of aeronautics, research similar to that now underway on the supersonic transport will probably be carried out to develop the technology for hypersonic transports. These hypersonic airplanes are to travel at Mach 6, 7, or 8 and to have ranges of about 6000 to 8000 miles. The technology for hypersonic transports will also be applicable to reusable first-stage boosters and orbital transports.

One concept of a recoverable orbital transport is shown in Figure 55. In this concept, the larger vehicle would take off in a conventional manner and accelerate to a hypersonic velocity. At this time, the smaller vehicle would separate and accelerate under its own power to orbital velocities to deliver men and cargo to and from orbiting space stations, or to carry out various other scientific or military missions in space. Both vehicles would land conventionally.



LIFTING RE-ENTRY VEHICLE CONCEPT

Fig. 55

A decision to develop such a vehicle is not anticipated in the near future, but the development of the propulsion and aerodynamic technology which will ultimately be needed is being undertaken. For example, the hypersonic air breathing hydrogen-fueled engine of the type to be tested on the X-15 might be applicable to the larger vehicle. Studies and experiments are likewise under way on lifting reentry bodies similar to the "piggy-back" vehicle. NASA may also propose in the future to develop an experimental manned orbital reentry vehicle of this type which would be used to develop the technology for lifting vehicles reentering the Earth's atmosphere at orbital velocities.

Satellite Applications

Among the more distant future developments in space exploration might be satellites in stationary orbits which broadcast television programs directly to viewers, such as that shown conceptually in Figure 56. This satellite would transmit about 10 kilowatts of power focused into a 3-to 5-degree beamwidth. This would permit coverage of an area about the size of India or western Europe. Such a satellite would require an orientation accuracy of plus or minus 2/10 degree with respect to the Earth and a 35-kilowatt power source that might be a SNAP-8 type nuclear supply. The satellite would weigh about 9600 pounds and would require a Saturn IB/Centaur launch vehicle.

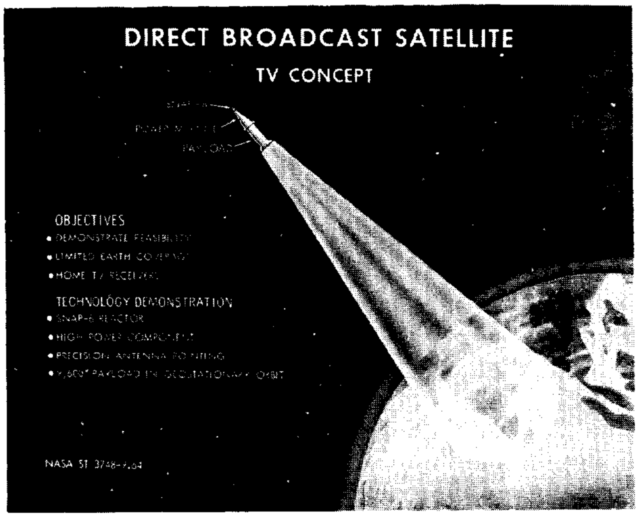


Fig. 56

Global navigation systems which could pinpoint the location of ships and aircraft and display this position information not only to the ships and aircraft themselves, but to other control and monitoring stations on the ground as well, could be developed also. Similarly, continued improvement of satellite meteorological systems should lead ultimately to routine continuous quantitative measurement of the weather over the entire surface of the Earth. Much of the technology needed for long-range developments such as these will be developed and proved by the missions to be undertaken within the next few years.

Unmanned Exploration

In the period beyond 1975, probes will probably be used initially to explore most of the more distant bodies in the solar system and to determine the space environment out of the plane of the ecliptic. Satellites in near-Earth orbit will be used to make detailed studies of active regions on the Sun and to monitor fluctuations in solar activity and in solar and galactic cosmic ray flux. Voyager class spacecraft will be flown to Mars and Venus at most opportunities, and unmanned spacecraft to explore the more distant planets, the asteroids and comets will be started.

New spacecraft will be developed for distant planet and asteroid missions utilizing many of the components and technologies that have been or will be developed in the Voyager programs. Spacecraft to be used for fly-by missions to comets, asteroids, and the planet Mercury will make measurements of the solar wind, interplanetary magnetic fields, and micrometeoroid flux during their flight through space. The missions to comets would also carry instruments to measure electron temperatures, to search for water and carbon dioxide vapor, and to collect and analyze dust particles. A fly-by mission to the planet Mercury or to an asteroid would carry television cameras for inspection of the surface, magnetometers and particle detectors to search for magnetic fields and trapped particle radiation, and radiometers to make surface temperature measurements. Of particular interest is the possibility of the existence of warm temperatures on the backside of Mercury. Characteristic velocities for these missions range from 40,000 to 48,000 feet per second.

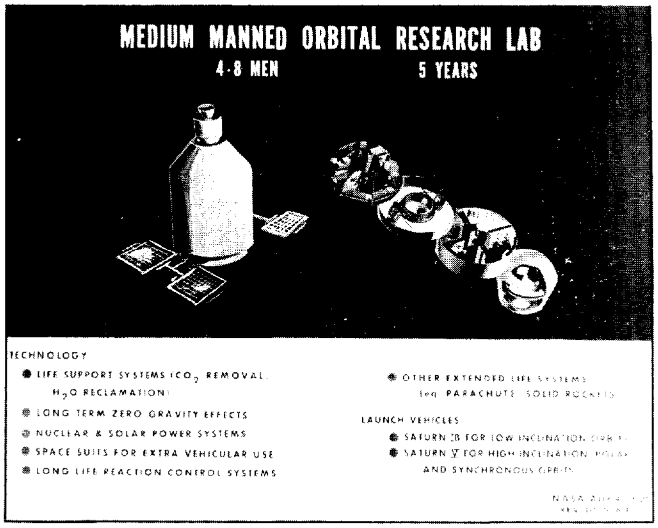
For Jupiter missions, it would be desirable to have a spacecraft weighing at least several thousand pounds. Advanced versions of this spacecraft might carry a retro-propulsion system similar to the one planned for the Voyager which could decelerate the spacecraft to Jovian orbital velocity. Ideal velocities for this mission range from 52,500 feet per second to 55,000 feet per second. Trip times to Jupiter would range from 500 to 600 days during the minimum energy launch dates that occur in the 1972-75 time period and again in the 1984-88 time period.

Instrumentation for this mission would be similar to that carried on other planetary missions and would make measurements of magnetic fields and trapped particle radiation, and take television pictures of the planet's surface.

This spacecraft could be launched by a Saturn IB/Centaur or Saturn V. Communication distances for these missions would range up to about 400 million miles. The more distant missions would require significant advances in our present communication capability if meaningful scientific data are to be returned. Communications system improvements might include larger antennas and more powerful transmitters on the spacecraft and larger receiving antennas on the Earth, probably using phased array techniques. Improved coding techniques would also be valuable to missions of this type. Radioisotope sources might be used for electric power.

Manned Space Exploration

As an outgrowth of the longer duration Apollo missions discussed earlier, a larger manned orbiting laboratory, similar to the one shown in Figure 57, might be developed. This spacecraft would accommodate six to nine men and remain in orbit for possibly 5 years. Resupply vehicles and rendezvous techniques would have to be developed to provide for crew rotation and for delivery of supplies and equipment. This particular laboratory concept would also contain a centrifuge, should it be found essential for reconditioning crew members to withstand the effects of gravitational fields after periods of weightlessness. It would also provide much roomier quarters with a shirt-sleeve environment for conducting a wide variety of experiments in space.



MEDIUM MANNED ORBITAL RESEARCH LAB

4-8 MEN 5 YEARS

TECHNOLOGY

- LIFE SUPPORT SYSTEMS (CO_2 REMOVAL, H_2O RECLAMATION)
- LONG TERM ZERO GRAVITY EFFECTS
- NUCLEAR & SOLAR POWER SYSTEMS
- SPACE SUITS FOR EXTRA VEHICULAR USE
- LONG LIFE REACTION CONTROL SYSTEMS
- OTHER EXTENDED LIFE SYSTEMS (eq PARACHUTE SOLID ROCKETS)

LAUNCH VEHICLES

- SATURN IB FOR LOW INCLINATION ORBITS
- SATURN V FOR HIGH INCLINATION POLAR AND SYNCHRONOUS ORBITS

Fig. 57

Some of the technological advancements which would be made in the development and operation of manned orbiting laboratories are listed in Figure 57. These include:

a. The development of dependable closed life support systems which recover oxygen and water from waste materials;

b. The study of the effects of long-term (up to one year or longer) weightlessness on man and, as mentioned, previously, the development of a human centrifuge or other techniques, as may be necessary to compensate for the prolonged effects of zero gravity;

c. The development of nuclear, solar, or other types of electrical power systems capable of supplying several kilowatts of power for operating the laboratory and its experimental equipment; and

d. The development of spacesuits to permit working outside the spacecraft, long-life reaction control systems for controlling and maintaining the spacecraft's attitude, and other systems such as parachutes and solid rockets which will work dependably after "soaking" for extended periods in the hard vacuum of space.

The Saturn IB would be adequate for placing this manned laboratory in low inclination orbits, while the Saturn V would be used for high inclination, polar, or stationary orbits.

A large telescope might be placed in orbit in conjunction with these laboratories. The extreme stability requirements of a large telescope would dictate that it not be rigidly attached but rather that it be tethered to the laboratory. This would allow the astronauts from the laboratory to change film, modify or change experiments, or perform any repairs that might be required.

The advantages of having telescopes above the Earth's atmosphere are that resolution can be improved and that observations can be carried out in the infrared and ultraviolet wavelengths that do not penetrate the Earth's atmosphere. The best resolution obtained by the 200-inch telescope on Mount Palomar, under ideal viewing conditions, is about 0.3 seconds of arc. A 100-inch diameter telescope which might be used in space with the manned orbiting laboratory would improve this resolution to .01 to .02 seconds of arc -- a factor of better than 10.

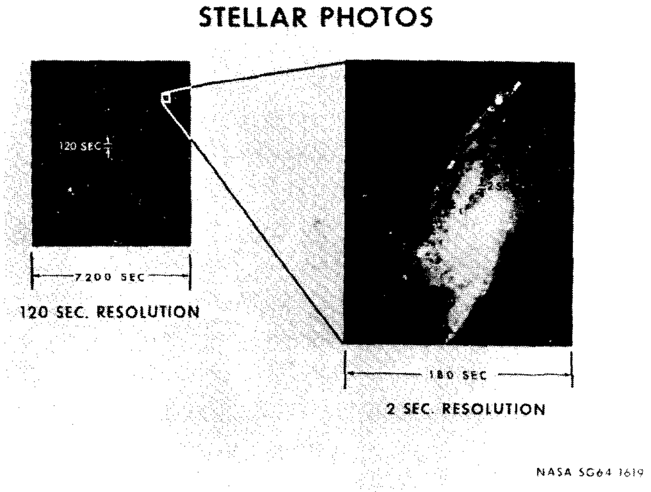
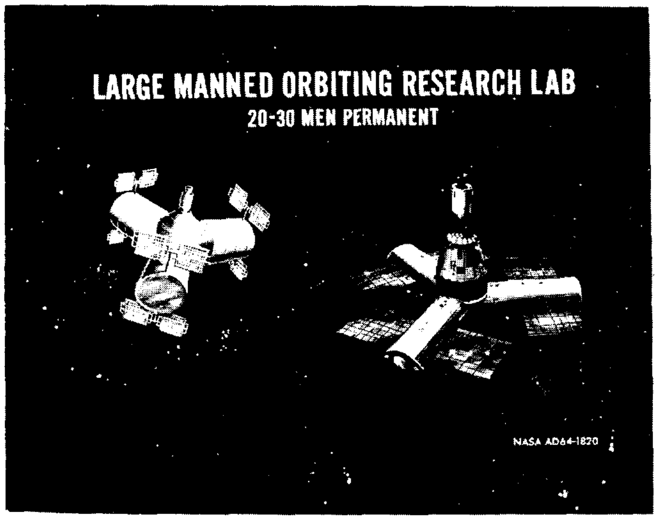


Fig. 58

Although the resolutions shown in Figure 58 do not correspond to the resolutions of the telescopes just discussed, the comparative improvement in resolution illustrated here is approximately equivalent to that of a 100-inch telescope in space over a 200-inch telescope on Earth.

Following the development of a manned orbiting research laboratory capability, a large manned orbiting research laboratory might then be developed, two possible configurations of which are illustrated in Figure 59. The configuration on the left illustrates how a large laboratory might be assembled in



LARGE MANNED ORBITING RESEARCH LAB

20-30 MEN PERMANENT

NASA AD64-1820

Fig. 59

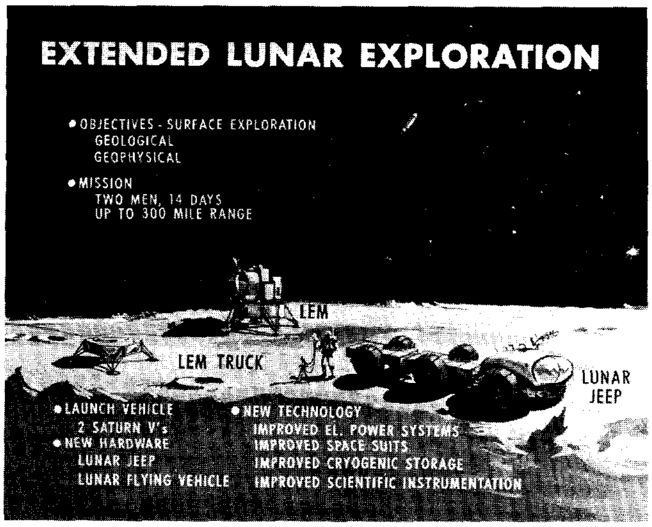
space using four of the six-to nine-man medium size orbiting laboratories which were discussed previously. The configuration on the right might also be assembled by joining together a new center section plus the three separate laboratories which comprise the "spokes" of the larger laboratory. Artificial gravity could be provided for the crew in laboratories such as these by rotating them about their axes.

Large laboratories of this sort would make use of both Saturn IBand Saturn V class vehicles and will require many major technological advances in reliability and in electrical power supplies, life support and other systems, as well as a much better understanding of the physiological and sociological factors involved in keeping in keeping man in space for extended periods of time.

Long range developments in lunar exploration will, of course, be determined to a large extent by what is learned from on-going Ranger, Lunar Orbiter, Surveyor, and Apollo programs, and from extended Apollo programs including use of the LEM truck for extended lunar stay time. It is also expected that the Moon would be explored in considerably greater detail through the use of roving vehicles for transporting men and equipment on the Moon's surface and through the establishment of semi-permanent or permanent lunar bases. In addition, these bases might be used as optical and radio astronomy observatories.

Manned exploration of the Moon beyond plus or minus 10 degrees of the lunar equator would require development of a direct flight capability rather than lunar orbit rendezvous. This capability might be provided by chemically uprating the Saturn V, by introducing a chemical fourth stage to the Saturn V, or by replacing the third stage of the Saturn V with a nuclear stage, as will be discussed later under the heading of Launch Vehicles and Propulsion.

As illustrated in Figure 60, an unmanned lunar excursion module may be used to land a lunar surface transportation vehicle, identified here as a lunar "jeep". This vehicle would carry sufficient food, water and oxygen, and provide shelter and scientific equipment needed for extended tours of the lunar surface. A second lunar excursion module would be used to transport the crew to the Moon. The crew members could then use the "jeep" to transport themselves and their needed scientific instruments and equipment to more remote spots for a much more extensive exploration. Preliminary studies indicate that a 3-ton "jeep", which could be delivered to the lunar surface by Saturn V, might carry enough fuel and life support



EXTENDED LUNAR EXPLORATION

- OBJECTIVES - SURFACE EXPLORATION
  GEOLOGICAL
  GEOPHYSICAL
- MISSION
  TWO MEN, 14 DAYS
  UP TO 300 MILE RANGE

- LAUNCH VEHICLE
  2 SATURN V's
- NEW HARDWARE
  LUNAR JEEP
  LUNAR FLYING VEHICLE
- NEW TECHNOLOGY
  IMPROVED EL. POWER SYSTEMS
  IMPROVED SPACE SUITS
  IMPROVED CRYOGENIC STORAGE
  IMPROVED SCIENTIFIC INSTRUMENTATION

Fig. 60

supplies to travel up to 300 miles and to sustain two men for possibly 2 weeks. Here again, it is obvious that major advances in technology will be required.

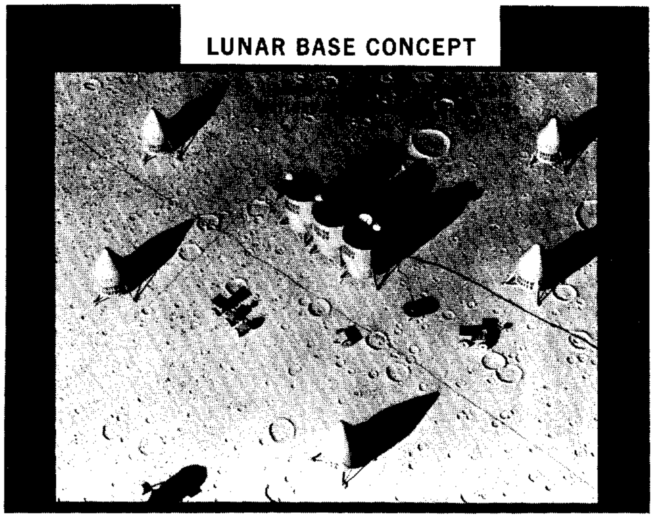


Fig. 61

These include:

a. Electrical power sources capable of producing many kilowatts;

b. Spacesuits flexible and durable enough to allow climbing in and out of the "jeep" and working on the lunar surface;

c. Reliable long-time storage of cryogenic supplies; and

d. Scientific instruments specifically developed for use on the lunar surface.

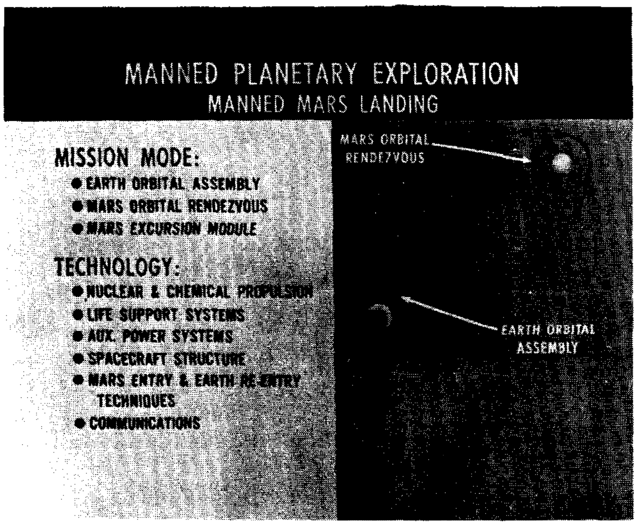
These advances are in addition to the basic engineering and technical problems involved in the development of the vehicle itself which must be capable of traveling over unfamiliar and unimproved terrain in the hard vacuum of the lunar surface.

Much further in the future, it may be desirable to establish a semi-permanent or permanent lunar base such as the one depicted in Figure 61. Various modules containing food, water, oxygen, and supplies, and other modules providing electrical power, communication facilities, and laboratory or shop facilities, might be delivered to the Moon's surface, one at a time, by using Saturn V class rockets as direct-flight logistics vehicles to establish a lunar base or colony of whatever size may be desired.

Fig. 62

One long-range possibility of particular interest to radio astronomers would be the construction of very large radio astronomy antenna arrays or telescopes similar to the ones in Figure 62. One of the Moon's craters might serve as the foundation of a large parabolic or spherical antenna similar to the one at Arecibo, Puerto Rico. The backside of the Moon appears especially useful for this purpose, since there would be no man-made radio noise to interfere with, and no ionosphere to attenuate, low-level radio signals coming in from outer space.

Possibly the most challenging long-term goal of the entire space program is manned exploration of the planets -- especially of the planet Mars. One of the most significant events in the history of mankind may well occur when man first sets foot on the planet Mars, possibly to view



MANNED PLANETARY EXPLORATION
MANNED MARS LANDING

MISSION MODE:
- EARTH ORBITAL ASSEMBLY
- MARS ORBITAL RENDEZVOUS
- MARS EXCURSION MODULE

TECHNOLOGY:
- NUCLEAR & CHEMICAL PROPULSION
- LIFE SUPPORT SYSTEMS
- AUX. POWER SYSTEMS
- SPACECRAFT STRUCTURE
- MARS ENTRY & EARTH RE-ENTRY TECHNIQUES
- COMMUNICATIONS

Fig. 63

plant and animal life unlike anything every seen on Earth. Although tremendous strides in space technology and many preliminary unmanned and manned missions of various types must be carried out before manned exploration of Mars can be seriously considered, some preliminary study has been given to such a mission.

Figure 63 summarizes some of the results of our thinking to date. The mission would likely include: (1) an initial rendezvous and assembly of the spacecraft in Earth orbit, (2) the trip of about 200 days through space from Earth to Mars, using nuclear propulsion, (3) landing of a Mars excursion module (similar to the concept of the LEM) and exploration of the planet's surface, (4) ascent to orbit for rendezvous with the orbiting portion of the spacecraft, and (5) return of the explorers to Earth.

The spacecraft would be assembled in Earth orbit before departure for Mars and would weigh millions of pounds, the exact weight depending upon factors such as the type of propulsion used, whether or not the thin Martian atmosphere can be depended upon for significant braking, and the year of the flight. In any event, as a practical matter, it appears that launch vehicles considerably more powerful than the Saturn V will be required to carry the necessary spacecraft hardware into Earth orbit.

In the propulsion of the spacecraft from Earth orbit to the planet, a clearly defined need arises for much more efficient propulsion, such as might be provided by nuclear rocket engines and by electric propulsion systems. For a Mars mission, the weight of a nuclear propulsion system would be must less than that of a comparable chemical system. Consequently, use of a nuclear stage for the Earth-orbit-to-Mars phase would greatly reduce the weight which must initially be placed in Earth orbit. It has been estimated that use of a nuclear stage for Earth-orbit-to-Mars propulsion would reduce the weight required in Earth orbit by at least 2 to 1 and possibly much more. The combination of nuclear rockets and electric propulsion could result in an even more significant weight reduction.

Many major technical advances are necessary before manned planetary missions can be undertaken. In addition to the development of more powerful launch vehicles and the perfection of nuclear rocket engines, these will include:

a. Development of dependable life support systems to provide food, water, fresh and uncontaminated cabin atmosphere, and waste elimination for multi-man crews and for mission durations of 2 to 3 years;

b. Electrical power systems capable of supplying many kilowatts of power for long periods;

c. Much higher capacity communication systems; and

d. More complete knowledge of the interplanetary environment is also needed to assure the design of safe, (i.e., adequately sealed and shielded) spacecraft structures. The gathering of these data will begin with the Mariner flight this year and continue with Voyager flights.

Launch Vehicles and Propulsion

With regard to the launch vehicles to be required by long-term future missions of the types listed here, most of the missions could, with one or two notable exceptions, be carried out using the available family of launch vehicles, assuming that the performance of these vehicles will be uprated as new propulsion technology is developed. The major exceptions are the ones noted in the discussion of manned lunar exploration beyond the equatorial region and manned planetary missions.

It has already been noted that a spacecraft weighing several million pounds would have to be placed in Earth orbit for a manned planetary expedition. Realistic evaluations of spacecraft weight indicate that a post-Saturn launch vehicle capable of placing on the order of a million pounds in Earth orbit will be needed. Some of the propulsion technology efforts now under way that would be applicable to development of such a launch vehicle are shown in the next figures.

Figure 64 shows the M-1 engine which is planned as a 1.5 million-pound thrust engine using hydrogen-oxygen propellants providing a specific impulse of over 400 seconds.

Also being investigated are large solid propellant motors. Shown in Figure 65 is a drawing of a "half-length" version of a 260-inch solid fuel rocket motor. It is about 70 feet long. The half-length motor would weigh about 1.7 million pounds and could develop about 3 million pounds of thrust. A full-length motor would deliver 6 to 7 million pounds of thrust for over 100 seconds of operation.

With regard to nuclear rocket propulsion two uses have been mentioned: manned planetary exploration and direct flights of manned spacecraft to the Moon. For a manned Mars mission, the initial weight in Earth orbit using nuclear propulsion would range from 1 1/2 to 5 1/2 million pounds, depending upon such factors as year of launch and mission size. Using chemical propulsion the spacecraft weight could vary between 3 and 24 million pounds.

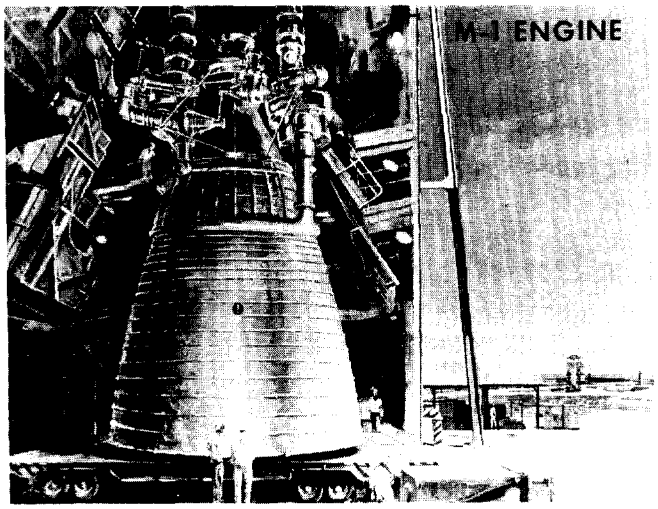


Fig. 64

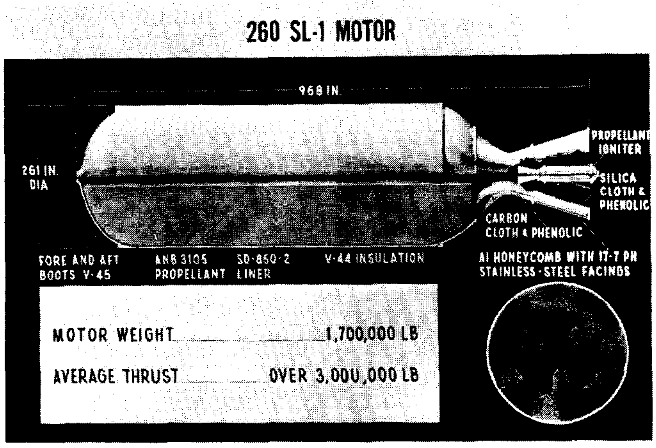


Fig. 65

A major point to emphasize, in addition to the large weight saving by the use of nuclear rocket propulsion, is that the limitations on spacecraft weight linked to changes in mission year, mode of flight accomplishment, and payload requirements are far less with nuclear rocket propulsion than with chemical propulsion. It is, therefore, conceivable that a single nuclear propelled spacecraft could be developed to accomplish the Mars mission at every opportunity with sufficient margin to assure that changes in the mission parameters will not result in aborted development efforts, major program changes, or restricted mission opportunities.

NASA and the Atomic Energy Commission have underway a joint program aimed at the development of nuclear rocket propulsion so as to be able to utilize the high performance of nuclear rocket systems and the improvement in vehicle payload capabilities that would result from their use in a wide variety of high-energy increment missions in space, such as manned planetary landing missions, direct flight lunar missions, and unmanned missions to the more distant regions of the solar system.

Two KIWI reactors and one NERVA reactor were tested successfully in 1964 at high power and temperature conditions. Figure 66 shows a picture of the KIWI reactor before its first power operation late in August 1964. This reactor has an outside diameter of about 4 feet and excluding the nozzle, it is about 6 feet long. It is designed for a power of about 1000 megawatts, or 50,000 pounds of thrust.

KIWI-B4E REACTOR AT TEST CELL C

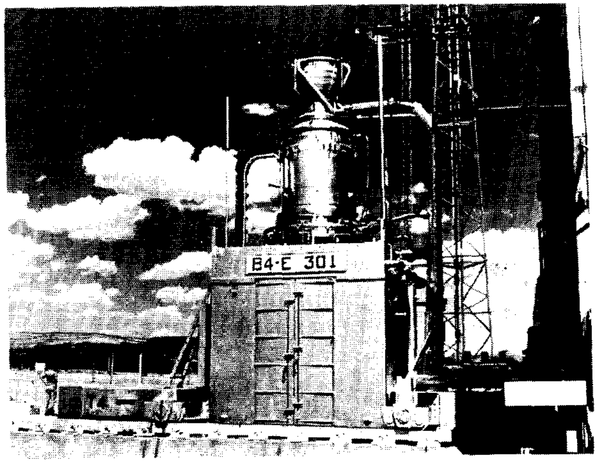


Fig. 66

Figure 67 is a picture taken during the test operation of the KIWI reactor. During this test, the reactor was operated for a total of approximately 12 minutes -- 8 minutes at the maximum power conditions. The duration of the test was limited only by the available supply of liquid hydrogen. The vacuum or altitude specific impulse equivalent to the operating conditions achieved in this test was about 740 seconds with an equivalent altitude thrust of approximately 51,000 pounds.

KIWI-B4E IN OPERATION

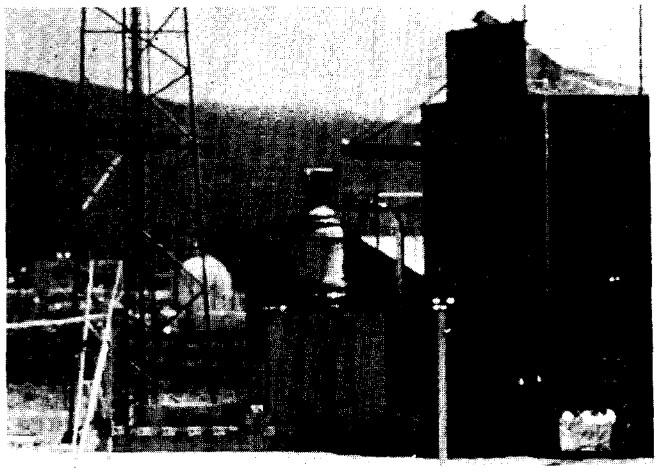


Fig. 67

On September 10, 1964, this reactor was rerun at full power for another 2 1/2 minutes, demonstrating the ability of these systems to be restarted. On disassembly, the reactor was found to be in excellent condition; however, some design and fuel element improvement is still required in the peripheral area of the reactor core. The tests demonstrated conclusively that the mechanical vibration problems encountered in previous nuclear rocket reactor tests had been successfully overcome.

These tests of the KIWI reactor were followed on September 24 by high power tests of the NERVA reactor to a vacuum equivalent specific impulse of approximately 765 seconds and a thrust of about 57,000 pounds. This reactor is the flight version of the KIWI reactor and will be used in the NERVA flight engine programs.

These recent successful reactor tests have demonstrated the high performance capabilities of nuclear propulsion systems and provide a high level of assurance that nuclear rocket propulsion can be relied upon for application in future space missions and vehicle designs.

It is important to recognize that the current AEC-NASA nuclear rocket program is providing the component and system technology that is required to develop engines of many required thrust levels. Operating limits and characteristics are being explored so that reliable and successful flight systems can be developed. The long lead times required in flight system development make it essential that the technology be available in advance of the specification of future missions.

Work is also underway on reactors that would be needed in higher power engines for the manned Mars mission. These higher power (5000 megawatt, or 250,000 pounds of thrust) and larger diameter reactors are now under investigation at the Los Alamos Scientific Laboratory as part of the AEC-NASA Phoebus program. A cluster of engines using these reactors would provide thrust sufficient for an Earth-orbit departure stage for a manned Mars mission. Single engines of this type could be used for Mars orbit entry and for the Mars orbit departure. The lower thrust, smaller diameter and weight NERVA engine (based on the KIWI-NERVA reactors already tested), would, however, provide some performance advantage if used in the Earth return stage.

In addition to the need for nuclear propulsion for the manned Mars mission, extensive lunar exploration or establishment of lunar bases may require the development of a direct-flight landing capability. At present, the Saturn V is capable of carrying a 28,000-pound payload directly to the lunar surface. It is estimated that the minimum weight required for direct manned flight and return is 31,000 pounds, as indicated by the horizontal broken line at the bottom of the cross-hatched area in Figure 68.

A Saturn V vehicle using a nuclear-powered third stage would provide a capability for landing approximately 45,000 pounds directly on the Moon. This 14,000 pound excess capability would permit carrying sufficient life support and electrical power equipment and supplies for three men to remain on the Moon for possible as long as 30 days.

It appears, therefore, that if extended lunar exploration and lunar base operations are undertaken, more economical

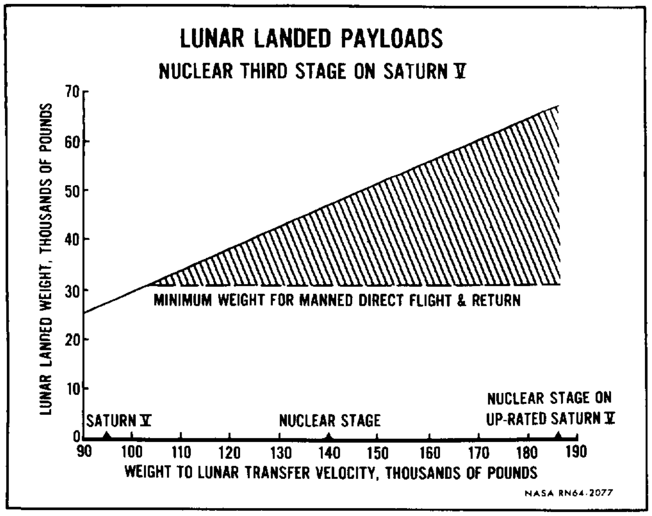


Fig. 68

operations, fewer launches and the ability to land on, and explore, all parts of the Moon could be provided by the use of a nuclear third stage on the Saturn V vehicle. This direct flight capability might be also provided by the chemical upgrading of the Saturn V. However, a nuclear third stage could provide advantages over the chemically upgraded version when used for unmanned deep-space exploration.

Figure 69 shows the payload that can be achieved for several representative missions, where a high-energy upper stage is added to both the Saturn V and the Saturn V/Nuclear. The increase in payload that results from the use of the nuclear stage is represented by the dashed portion of the bars. As an example, it is interesting to point out that the Mars orbit payload could be increased from approximately 30,000 to 50,000 pounds by use of a nuclear third stage. The figure shows the wide range of missions, including extra-ecliptic, solar probe, and other planetary missions, for which the nuclear-powered stage provides large increases in the payload capability of Saturn V. Such performance margins would be useful in our future space activities in providing increased mission flexibility and capability.

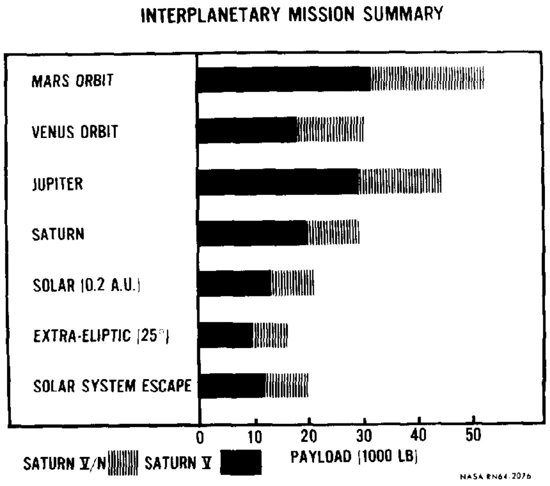


Fig. 69

Studies of propulsion for long-range missions indicate that nuclear electric propulsion with its very high specific impulse may offer some advantages over nuclear rocket and chemical propulsion--especially for very long distance unmanned missions to Jupiter, Saturn, or beyond.

Practical use of electric propulsion will require very high-capacity nuclear power sources capable of dependably producing several megawatts of electrical energy for period of 10, 20 or 30 thousand hours. The advantages of electric propulsion over nuclear rocket propulsion will depend heavily upon the power source specific weight (normally expressed in pounds per kilowatt). Estimates are that reactor power supplies currently under development will weigh about 30 to 40 pounds per kilowatt; with weights of 30 pounds per kilowatt or less, electrical propulsion will be competitive with other advanced types of propulsion.

Much of the payload weight which might be delivered by electrical propulsion will necessarily consist of the weight of the nuclear reactor electrical power source. However, one of the major needs of future space exploration is for high-capacity sources of electrical power. The nuclear power source would therefore serve a dual role in that it would also be available for purposes such as operation of communications, instruments, and life support systems as well as for propulsion.

Development of light-weight, megawatt-level, nuclear electric power sources having high reliability for thousands of hours of continuous operation is a long-term undertaking. However, technological development experience has repeatedly shown that with reasonably-paced research efforts, solutions to seemingly insurmountable technological problems often turn out to be straightforward and practical.

Advanced technological developments, such as the propulsion work just described, are essential if this country is to maintain a logical continuity of effort and to retain flexibility in selecting its future missions and national space goals. For example, the nuclear rocket program was started in 1955 by the AEC and the Air Force. Now, 10 years later and after extensive technical effort, data have been obtained that experimentally verify the analytical predictions of performance for this type of propulsion. In looking ahead, important uses for these systems are now clearly seen. Considering the high costs and long lead times that will be involved in the development of operational advanced propulsion systems for future missions, such as nuclear rocket and nuclear electric systems, significant cost advantages over the long term can be assured if technical problems that may arise in engine and vehicle system development and operation are uncovered and solved as part of a technology effort. Experience has clearly demonstrated that encountering such problems for the first time in the course of urgent operational system development results in large cost overruns and slipped schedules. Decisions on missions should be made on the basis of technology that is in hand or close to being available.

If we are to undertake advanced space missions such as those described in this section, the technological basis -- including system engineering as needed - -must be established in the years before firm decisions are made. NASA's propulsion, vehicle, power, and other technological programs are all being directed in recognition of these points.

Technology

This section of the report is concerned with the research and technological advances which must be made to support the long-range missions. One point to be emphasized is that although the technological developments to be discussed are included under the "long-range" category, the research and technology development must be supported now and continued throughout the immediate future so that the needed technology will be available in time to undertake longer range missions of the type discussed here or others, not now foreseen, which may later become important. In a well-planned program, development of the needed technology should precede by several years a commitment to an advanced mission. The level of the technological development will determine to a large extent what missions can or cannot be undertaken at a given time.

In this section, the major technological advances needed in several areas for near-future and long-range future programs will be reviewed and some of the advances now being made, or needed, will be indicated.

Possibly the most clearly defined need for a major advance in technology is in the area of spacecraft electrical power sources. Plotted in Figure 70 are typical requirements for several missions. The current Mariner spacecraft

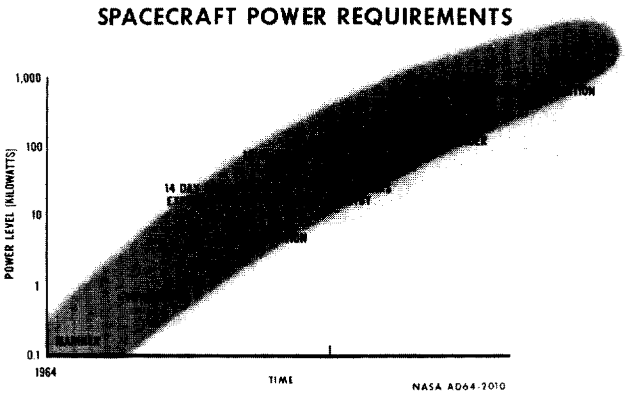


Fig. 70

will use on the order of a few hundred watts of power, which will be obtained from solar cells. Future unmanned planetary exploration spacecraft, such as Voyager, will require about one kilowatt, and six-to nine-man orbiting space laboratories will require many kilowatts. As more advanced missions (such as extended lunar expeditions, manned Mars fly-by missions, or large manned space stations) are undertaken, power requirements will approach 50 to 100 kilowatts. In the more distant future, missions such as the establishment of a lunar base or a manned planetary landing will require powers in excess of 100 kilowatts. Power needed for electrical propulsion would be on the order of several megawatts, which is completely outside the scale of this figure.

Spacecraft power requirements on the order of a few hundred watts or less have been met, and may continue to be met, by solar cell arrays, except for those spacecraft which operate too close to, or too far from, the Sun. Also, as larger power requirements arise, solar cells are less useful because of the very large surface areas and structural weights involved.

Fuel cells (such as those planned for use in the Apollo spacecraft) will be useful for delivering several kilowatts of power for periods of up to perhaps 1,000 hours, but require cryogenically-stored supplies of liquid hydrogen and liquid oxygen. (On the other hand, the hydrogen-oxygen reaction produces water which is useful in manned vehicles.) Continuing research and development on fuel cells will be primarily aimed at reducing the weight of the cells, at increasing the electrical energy produced for a given quantity of hydrogen and oxygen, at increasing their operating life times, and at developing dependable re-start characteristics.

Radioisotope sources have a great potential range of application from the point of view of weight, size, and life-time; our studies have shown that many future missions depend upon the development of isotope power sources in the 500 to 1,500 watts power range.

However, in addition to the basic developmental problems normally associated with any new device, radioisotope power supply development involves two additional difficult problems: one is the radiation shielding problem, especially if beta emitters are used, and the other is that the National production rate of preferred isotopes, such as plutonimum 238 or polonium 210, may be inadequate for use-rates greater than a few power supplies per year. Additional National facilities maybe required to produce an adequate supply of these isotopes.

Nuclear reactor power plants will be needed for missions such as extended lunar base operations, manned interplanetary flights, or electric propulsion. Preliminary design efforts include the SNAP-8 system (35 kilowatts) and higher-power systems such as the SNAP-50 (300 kilowatts) system. Shielding weights are a significant problem in the use of these systems--especially where use in manned vehicles is contemplated. For lunar base operation, reactors may be buried in the lunar soil to provide the necessary shielding.

Another area where definite technological advances must be made for future long-distance missions is that of spacecraft-to-Earth communications. Available communications technology has, in general, been adequate for transmitting to Earth scientific measurements made by current spacecraft, with the major exception being Mariner IV.

As a result of past efforts in the development of large parabolic receiving antennas and sensitive electronic systems of the Deep Space Instrumentation Network, it was possible on Ranger VII to transmit, within about 15 minutes, more than 4,000 good quality television pictures over the

250,000 miles from the Moon to the Earth. However, at planetary distances of tens or hundreds of millions of miles, the information transmitting capacity of the communications link decreases drastically. If all other factors remain constant, the capacity of a radio communications link decreases as the square of the transmission distance. This means that the Mars-to-Earth data transmission capacity of present facilities is on the order of 1/1,000,000 of their Moon-to-Earth capacity. If the Ranger VII spacecraft had been flown to Mars, only a small fragment of one picture could have been transmitted to the Earth in the time interval of approach. The Mars Mariner launched last November will transmit about one TV picture every 10 hours, using an actual transmission time of 8 1/2 hours for each picture.

Figure 71 shows the data transmission capacity, in bits per second, for the maximum Mars-Earth distance of 250,000,000 miles. The lower shaded horizontal bar shows that on the order of 10 to 100 bits per second are required to transmit about one TV picture per day. Voyager spacecraft will require at least a few thousand bits per second.

The middle horizontal shaded bar at 10^5 bits per second shows the data transmission requirement for a typical manned planetary spacecraft. The upper horizontal shaded bar between 10^6 and 10^7 bits per second indicates the capacity needed if a large number of television pictures, similar to Ranger VII photos, are to be transmitted over the Mars-to-Earth distance.

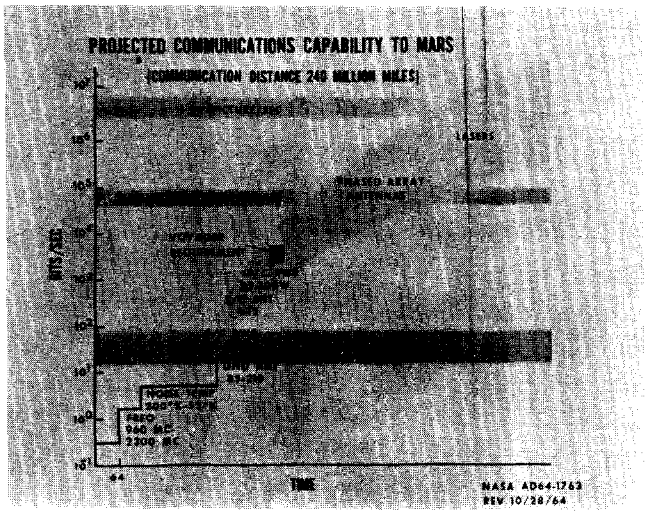


Fig. 71

Past improvements and present capabilities are indicated by the solid line, which shows a current capability for transmission of approximately one television picture in 8 1/2 hours. Also shown are some of the technological advances which might be undertaken to meet future communication requirements. These include increasing the spacecraft transmitted power to 100 watts, increasing the size of the spacecraft antenna diameter from 4 to 12 feet, and use of 210-foot-diameter antennas on the ground.

Requirements beyond about 10^4 bits per second are beyond the capabilities of techniques and facilities anticipated within the next several years. Some of the needed additional capacity may be derived from the use of still larger antennas on the spacecraft and even higher-powered spacecraft transmitters. These, of course, require still larger electrical power sources aboard the spacecraft. Beyond this, further improvements might come from the use of larger receiving antenna areas on the ground. Larger single-dish antennas do not appear practical but the needed larger areas might be realized by arraying a number of 100 - to 200 - foot antennas whose outputs would be combined to provide the equivalent of 500-to 1,000-foot diameter antennas.

Beyond about 10^5 bits per second, further increases in communications link capacity might come from the use of lasers and light frequencies for data transmissions. There are, however, many problems associated with laser communication systems whose solutions are as yet not clearly foreseen. For example, light beams do not penetrate clouds or fog, the power output of current lasers is low, and modulation and de-modulation techniques are as yet crude. In addition, the basic advantages of light frequencies over radio frequencies for communications are derived from the concentration of transmitted light energy within an extremely narrow beam; to use this beam requires that it be pointed with extremely high precision at the exact spot where reception is desired.

Figure 72 illustrates the increase in precision with which spacecraft instruments must be aimed or pointed. The required angular precision, in degrees, is shown for several space missions. Current operational requirements can be met with pointing precision on the order of 1/10 to one degree. The Advanced Orbiting Solar Observatory (which, as previously discussed, will observe an area of the Sun's surface only 20 arc-seconds in diameter) will require a pointing accuracy on the order of 1/1000 degree. The Orbiting Astronomical Observatory requires an even higher precision, on the order of 1/10,000 degree.

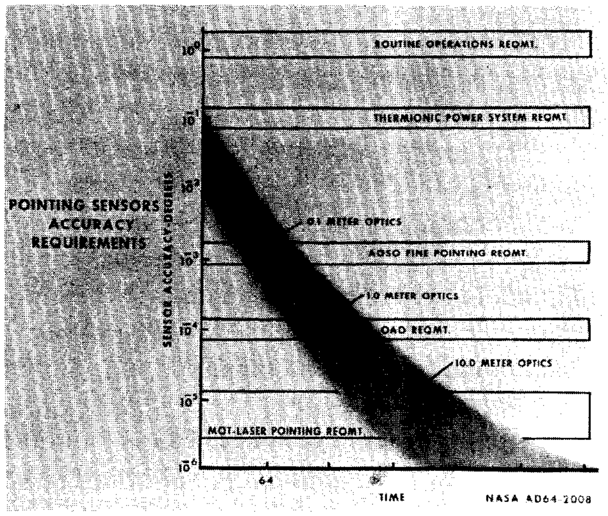


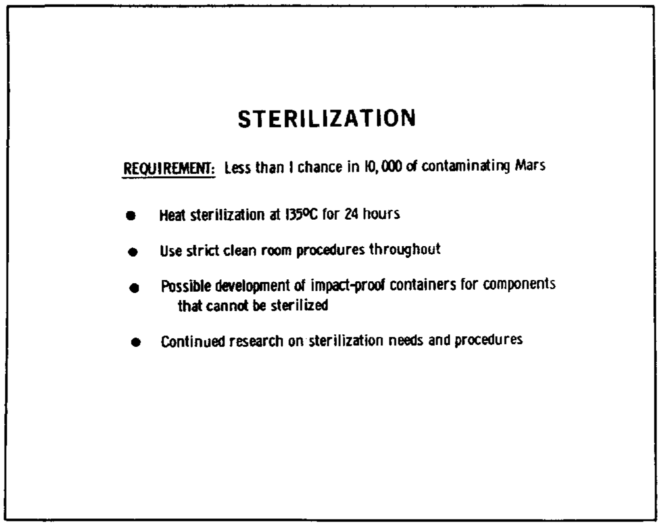
Fig. 72

Two types of pointing requirements are to be noted: the OAO, once it has located a particular star to be observed, can use the point of light provided by the star as a target to maintain its pointing precision; other requirements, such as for the AOSO, are more difficult to meet since instruments must be pre-programmed to point at a particular spot where no pinpoint "target" is available.

Systems such as a manned orbital telescope or a laser communications system require even higher pointing precisions, on the order of 1/100,000 of a degree. This serves to illustrate the interdependence of the technical requirements: the advantages of laser communications systems cannot be realized until the technology which provides for very precise pointing has been developed.

NASA's future efforts aimed at meeting some of these requirements will include research and development on inertial sensors which use gas or electrostatic bearings, or possibly super-conducting magnetic suspension methods, as well as star trackers which automatically recognize and lock on various star patterns or constellations. Work is also being done on sensors which can recognize and lock on the horizon line of the Earth, Moon, or another planet in order to provide a reference for control of the vehicle's attitude.

Sterilization of planetary spacecraft, as necessary to prevent contaminating another planet represents another difficult technical problem. As indicated in Figure 73, a specification has been established that the probability of landing contaminating bacteria on Mars should be held to less than one chance in 10,000. To meet this requirement, planetary vehicles must be sterilized even more thoroughly than is required by, or available from, the best hospital operating room techniques.



STERILIZATION

REQUIREMENT: Less than 1 chance in 10,000 of contaminating Mars

- Heat sterilization at 135°C for 24 hours
- Use strict clean room procedures throughout
- Possible development of impact-proof containers for components that cannot be sterilized
- Continued research on sterilization needs and procedures

Fig. 73

Thus far, the only known effective method of sterilization is the application of moist heat at 135° C for 24 hours. This generates serious reliability problems, since many components or materials such as batteries, plastics, pyrotechnics, scientific instruments and many electronic parts are either seriously damaged or completely disabled by high-temperature sterilization processes. Additional research is necessary, either to develop components which are unaffected by high temperatures, or to develop other effective sterilization methods which use lower temperatures and are less damaging to to critical spacecraft components.

The sterilization requirement also sharply increases the difficulty of virtually all phases of the spacecraft fabrication, calibration, assembly and repair, since strict clean-room procedures--"untouched by human hands"-- must be used throughout.

Components such as batteries which cannot be made to withstand other sterilization procedures may have to be encased in impact-proof containers which will not break open even under the impact of hard landings on other planets.

All manned spaceflight missions require life-support systems to supply food, water, breathable and uncontaminated cabin atmosphere, and to dispose of waste materials. Figure 74 shows the advances which must be made in life support systems for longer-duration manned space missions of the future. The period of time during which the system must operate continuously without resupply, repair, or readjustment is shown for various types of manned space missions.

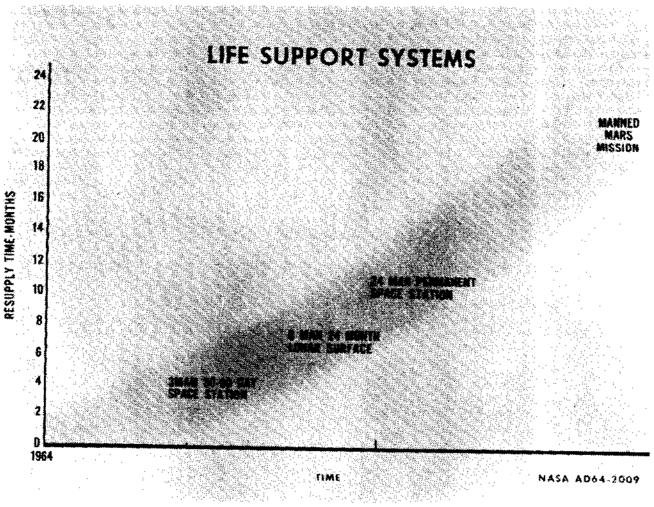


Fig. 74

Earlier systems must support two or three men for 30 to 90 days; extended explorations of the lunar surface or large permanent manned space stations might be expected to operate for much longer periods -- 4 to 8 months-- without resupply; and manned expeditions to the planets must of course operate for full round-trip travel times of from one to 3 years.

For the shorter duration missions (up to 30 days), or for a near-Earth mission where resupply can be comparatively frequent, food, water, and oxygen can be carried along with the vehicle or delivered by additional supply vehicles launched from Earth. However, for longer missions of 60 days or more, it is not practical to carry along all needed supplies, so that life-support systems which provide for recovery and reuse of water and oxygen must be used.

The research and development work to be done here will include systems and techniques for reclaiming drinking water from wash water or waste products; techniques for recovering oxygen from expired carbon dioxide, and methods for detecting and removing dangerous contaminating gases from the cabin atmospheres. Development of dependable systems must also include extensive testing of these systems on the ground, using men living and working under closely simulated space ship conditions for long periods of time.

Considerable research effort will also be devoted to the study of man himself--his physiological and psychological problems. Future efforts will be aimed at obtaining a better understanding of man, and at determining his best utilization in advanced aerospace systems. The problems to be studied will include:

a. The effects of weightlessness, including possible states of disorientation, decalcification of bones, and decreases in cardiovascular tone. Bone decalcification will be studied on Earth by means of prolonged bed rest and immobilization. The effects of weightlessness on the cardiovascular system cannot be studied on Earth but will require a prolonged zero-G environment available only in manned vehicles in space;

b. Development of work-rest programs most effective for spacecraft crews. With the loss of diurnal rhythm while in space, unusual work-rest cycles may prove more efficient than those normally used on Earth;

c. Possible physical problems such as a depth perception, space myopia, and high contrast effects;

d. Effects of radiation--particularly of proton radiation ---on living tissues. These studies will be carried out using cyclotron experiments, supplemented by theoretical calculations, on tissue; and

e. Parasite-host relationships existing in man. This subject has been given added emphasis by a recent five-man, 30-day chamber test which revealed that Staph Aureus dominated other micro-organisms in the body and eventually became the only bacteria present.

Improvement of space system reliability is another area which will require a continued, vigorous research and development effort. Many of the prospective future missions are of much longer duration than previous missions and will consequently require systems capable of operating for much longer periods of time without failure. For example, since even a one-way trip to the planet Mars requires about 7 months, an unmanned planetary spacecraft must operate successfully for at least this period of time to obtain even a minimum degree of success, as compared to an Earth satellite which normally will obtain some useful data even if its useful lifetime is no more than a few days or a few weeks.

Future reliability requirements dictate that the failure-free operating lifetimes of many individual components and parts used in spacecraft systems must be improved by factors of 100 to 1,000. As outlined in Figure 75, future efforts aimed at realizing these levels of improvement will include study and research on the basic physics of the aging and deterioration of electronic parts and materials; continued effort to develop more reliable design, fabrication, and testing procedures; an increased emphasis on the use of redundancy and other techniques for ensuring long operating lives; and development of effective management procedures which ensure that effective reliability and quality control procedures are strictly followed at every stage of spacecraft design and fabrication.

RELIABILITY

RESEARCH ON THE PHYSICS OF AGING AND DETERIORATION OF ELECTRONIC PARTS AND MATERIALS IN SPACE

DEVELOPMENT OF MORE RELIABLE DESIGN, FABRICATION, AND TESTING PROCEDURES

COMPONENTS AND SYSTEMS•SPECIFICALLY DESIGNED FOR A LONG LIFE

IMPROVEMENT OF MANAGEMENT TECHNIQUES TO INSURE THAT MOST EFFECTIVE RELIABILITY AND QUALITY CONTROL PROCEDURES ARE USED

Fig. 75

VI SUMMARY

Our study of future programs has covered three major categories as illustrated earlier in Figures 4, 34, and 54, repeated here for ease of reference. These have covered:

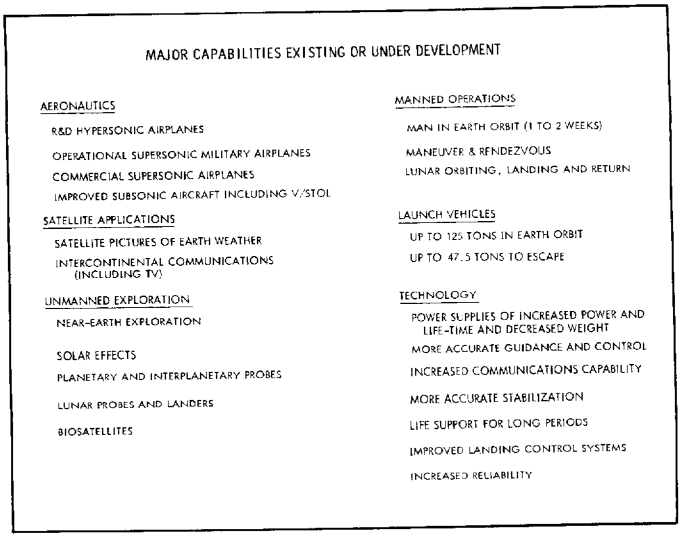
a. A review of the capabilities being developed by current programs;

b. Intermediate missions which would support National objectives in space and afford steady progress toward longer-range goals, and at the same time make most effective use of capabilities developed thus far; and

c. Long-range missions which may comprise the Nation's space exploration goals in the decades ahead.

In the areas of aeronautics, satellite applications, unmanned and manned space exploration, launch vehicles, and research and technology development, it is possible to trace horizontally the development path from 1958 to a decade or further into the future. It is obvious that there is increased uncertainty as the plans are projected into the future.

The details of these new missions, such as specific spacecraft designs and exact mission plans will, of course, be the subject of continued study by Headquarters and Field Centers of NASA, by interested government agencies, by universities, and by industry. Continued



MAJOR CAPABILITIES EXISTING OR UNDER DEVELOPMENT

AERONAUTICS
R&D HYPERSONIC AIRPLANES
OPERATIONAL SUPERSONIC MILITARY AIRPLANES
COMMERCIAL SUPERSONIC AIRPLANES
IMPROVED SUBSONIC AIRCRAFT INCLUDING V/STOL

SATELLITE APPLICATIONS
SATELLITE PICTURES OF EARTH WEATHER
INTERCONTINENTAL COMMUNICATIONS (INCLUDING TV)

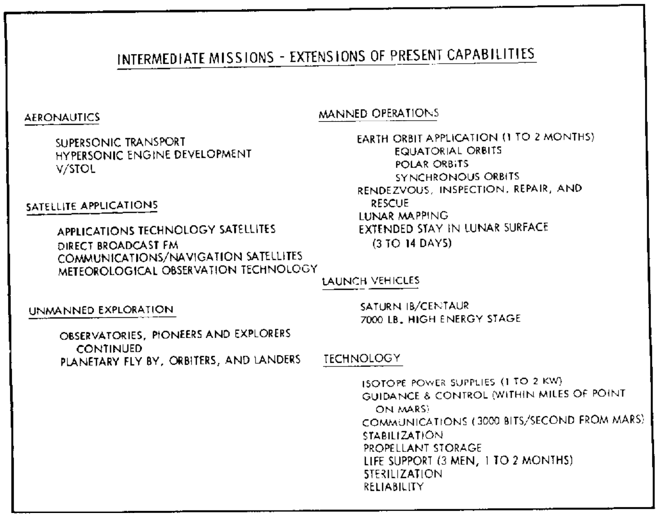
UNMANNED EXPLORATION
NEAR-EARTH EXPLORATION
SOLAR EFFECTS
PLANETARY AND INTERPLANETARY PROBES
LUNAR PROBES AND LANDERS
BIOSATELLITES

MANNED OPERATIONS
MAN IN EARTH ORBIT (1 TO 2 WEEKS)
MANEUVER & RENDEZVOUS
LUNAR ORBITING, LANDING AND RETURN

LAUNCH VEHICLES
UP TO 125 TONS IN EARTH ORBIT
UP TO 47.5 TONS TO ESCAPE

TECHNOLOGY
POWER SUPPLIES OF INCREASED POWER AND LIFE-TIME AND DECREASED WEIGHT
MORE ACCURATE GUIDANCE AND CONTROL
INCREASED COMMUNICATIONS CAPABILITY
MORE ACCURATE STABILIZATION
LIFE SUPPORT FOR LONG PERIODS
IMPROVED LANDING CONTROL SYSTEMS
INCREASED RELIABILITY

Fig. 4



INTERMEDIATE MISSIONS - EXTENSIONS OF PRESENT CAPABILITIES

AERONAUTICS
SUPERSONIC TRANSPORT
HYPERSONIC ENGINE DEVELOPMENT
V/STOL

SATELLITE APPLICATIONS
APPLICATIONS TECHNOLOGY SATELLITES
DIRECT BROADCAST FM
COMMUNICATIONS/NAVIGATION SATELLITES
METEOROLOGICAL OBSERVATION TECHNOLOGY

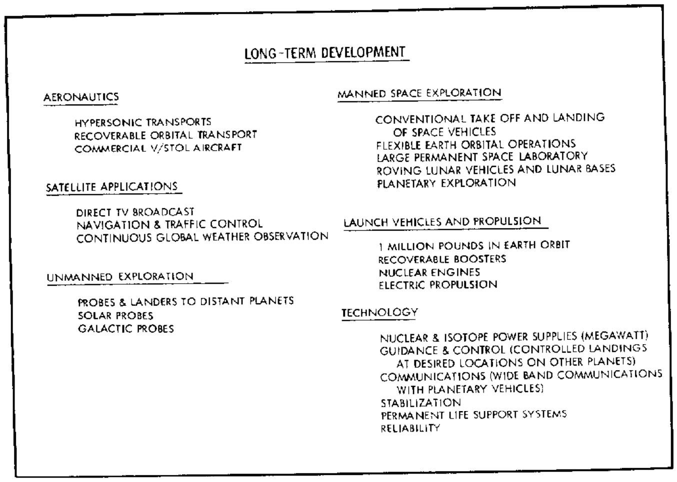
UNMANNED EXPLORATION
OBSERVATORIES, PIONEERS AND EXPLORERS CONTINUED
PLANETARY FLY BY, ORBITERS, AND LANDERS

MANNED OPERATIONS
EARTH ORBIT APPLICATION (1 TO 2 MONTHS)
  EQUATORIAL ORBITS
  POLAR ORBITS
  SYNCHRONOUS ORBITS
RENDEZVOUS, INSPECTION, REPAIR, AND RESCUE
LUNAR MAPPING
EXTENDED STAY IN LUNAR SURFACE (3 TO 14 DAYS)

LAUNCH VEHICLES
SATURN IB/CENTAUR
7000 LB. HIGH ENERGY STAGE

TECHNOLOGY
ISOTOPE POWER SUPPLIES (1 TO 2 KW)
GUIDANCE & CONTROL (WITHIN MILES OF POINT ON MARS)
COMMUNICATIONS (3000 BITS/SECOND FROM MARS)
STABILIZATION
PROPELLANT STORAGE
LIFE SUPPORT (3 MEN, 1 TO 2 MONTHS)
STERILIZATION
RELIABILITY

Fig. 34



LONG-TERM DEVELOPMENT

AERONAUTICS
HYPERSONIC TRANSPORTS
RECOVERABLE ORBITAL TRANSPORT
COMMERCIAL V/STOL AIRCRAFT

SATELLITE APPLICATIONS
DIRECT TV BROADCAST
NAVIGATION & TRAFFIC CONTROL
CONTINUOUS GLOBAL WEATHER OBSERVATION

UNMANNED EXPLORATION
PROBES & LANDERS TO DISTANT PLANETS
SOLAR PROBES
GALACTIC PROBES

MANNED SPACE EXPLORATION
CONVENTIONAL TAKE OFF AND LANDING OF SPACE VEHICLES
FLEXIBLE EARTH ORBITAL OPERATIONS
LARGE PERMANENT SPACE LABORATORY
ROVING LUNAR VEHICLES AND LUNAR BASES
PLANETARY EXPLORATION

LAUNCH VEHICLES AND PROPULSION
1 MILLION POUNDS IN EARTH ORBIT
RECOVERABLE BOOSTERS
NUCLEAR ENGINES
ELECTRIC PROPULSION

TECHNOLOGY
NUCLEAR & ISOTOPE POWER SUPPLIES (MEGAWATT)
GUIDANCE & CONTROL (CONTROLLED LANDINGS AT DESIRED LOCATIONS ON OTHER PLANETS)
COMMUNICATIONS (WIDE BAND COMMUNICATIONS WITH PLANETARY VEHICLES)
STABILIZATION
PERMANENT LIFE SUPPORT SYSTEMS
RELIABILITY

Fig. 54

space exploration will be an evolutionary process in which the next step is based largely on what was learned from the experience of preceding research and flight missions. The pace at which these new programs will be carried out will necessarily depend upon many other factors, such as the allocation of budgetary and manpower resources and the changing National needs of the future.

This study has not revealed any single area of space development which appears to require an overriding emphasis or a crash effort. Rather, it appears that a continued balanced program, steadily pursuing continued advancement in aeronautics, space sciences, manned space flight, and lunar and planetary exploration, adequately supported by a broad basic research and technology development program, still represents the wisest course. Further, it is believed that such a balanced program will not impose unreasonably large demands upon the Nation's resources and that such a program will lead to a pre-eminent role in aeronautics and space.