[signed]
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Document II-4

Document Title: George M. Low, Program Chief, Manned Space Flight, Memorandum for Associate Administrator, "Transmittal of Report Prepared by Manned Lunar Working Group," 7 February 1961, with Attached Report, "A Plan for a Manned Lunar Landing."

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George Low had been among the first in NASA to openly advocate a lunar landing goal and was a vocal proponent of that goal. In October 1960 he formed a Manned Lunar Working Group Task Force. The task force transmitted its findings to NASA Associate Administrator Robert Seamans on 7 February; its report was the first fully developed plan for how NASA proposed to send humans to the Moon. Low and his group concluded that "The present state of knowledge is such that no invention or breakthrough is believed to be required to insure the over-all feasibility of safe manned lunar flight." This was an important consideration two months later as President Kennedy considered whether to commit the United States to sending Americans to the Moon. The group also estimated that the plan could be carried out over 10 years for an average cost of $700 million per year, for a total cost of $7 billion.

[Originally marked "For Internal Use Only"]

February 7, 1961

MEMORANDUM for Associate Administrator

Subject: Transmittal of Report Prepared by Manned Lunar Working Group

1. The attached report, entitled "A Plan for Manned Lunar Landing" was prepared by the Manned Lunar Working Group. It accurately represents, to the best of my knowledge, the views of the entire Group.

2. Copies of a draft of this report were submitted to the Program Directors, NASA Headquarters, and to the Directors of Marshall Space Flight Center and Space Task Group. In cases where comments were submitted, these comments were incorporated in the report.

3. The Group stands ready to make a presentation of the material presented in the report at any time you might so desire.

4. No additional work is planned until further instructions are received.

/Signed/
George M. Low
Program Chief
Manned Space Flight

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON 25, D. C.

A PLAN FOR MANNED LUNAR LANDING*

INTRODUCTION

In the past, man's scientific and technical knowledge was limited by the fact that all of his observations were made either from the earth's surface or from within the earth's atmosphere. Now man can send his measuring equipment on satellites beyond the earth's atmosphere and into space beyond the moon on lunar and planetary probes. These initial ventures into space have already greatly increased man's store of knowledge.

In the future, man himself is destined to play a vital and direct role in the exploration of the moon and of the planets. In this regard, it is not easy to conceive that instruments can be devised that can effectively and reliably duplicate man's role as an explorer, a geologist, a surveyor, a photographer, a chemist, a biologist, a physicist, or any of a host of other specialists whose talents would be useful. In all of these areas man's judgment, his ability to observe and to reason, and his decision-making capabilities are required.

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*Prepared by the Lunar Landing Working Group, January 1961.

[2]

The initial step in our program for the manned exploration of space is Project Mercury. This Project is designed to put a manned satellite into an orbit more than 100 miles above the earth's surface, let it circle the earth three times, and bring it back safety. From Project Mercury we expect to learn much about how man will react to space flight, what his capabilities may be, and what should be provided in future manned spacecraft to allow man to function usefully. Such knowledge is vital before man can participate in other, more difficult, space missions.

Project Mercury is the beginning of a series of programs of ever-increasing scope and complexity. The future can be expected to include the milestones shown in Figure 1.

The next step after Mercury is Project Apollo. The multi-manned Apollo spacecraft will provide for the development and exploitation of manned space flight technology in earth orbit; it also provide the initial step in a long-range program [3] for the manned exploration of the moon and the planets. In this paper we will focus on a major milestone in the program for manned exploration of space - lunar landing and exploration. This milestone might be subdivided into two phases:

1. Initial manned landing, with return to earth;

2. Manned exploration.

This report will be limited to a discussion of the initial manned lunar landing and return mission, with the clear recognition that it is a part of an integrated plan leading toward manned exploration of the moon.

An important element in the manned space flight program is the establishment of a space station in an earth orbit. Present thinking indicates that such a station can be established in the same time period as manned lunar landings can be made, and also that many of the same technological developments are required for both purposes. Although both missions were broadly considered in planning developments for the lunar program, only the lunar requirements are discussed in this paper.

An undertaking such as manned lunar landing requires a team effort on an exceedingly broad scale. The various elements of [4] this effort are indicated in Figure 2. [not provided] The basic capability is provided through the parallel development of a spacecraft and a launch vehicle. Both of these developments must proceed in an orderly fashion, leading to hardware of increasing capability. Supporting these developments are many other scientific and technical programs and disciplines, as shown in the figure. The implementation of the manned spacecraft program requires information that will be obtained in the unmanned spacecraft and life science programs. The development of launch vehicle capability requires new engines, techniques to launch from earth orbit, and might include launch vehicle recovery developments. Both the spacecraft and the launch vehicle programs can progress only as new knowledge is obtained through advanced research.

All of these program elements currently exist in the total NASA program. Work is under way in areas that are pertinent to the development of the capability for manned lunar landing. In this report the interrelationship between the various programs will be studied. Key items will be examined in detail, to determine the proper phasing between the development of new systems, and the availability of the background information required for these developments.

[5]

NASA RESEARCH

Already there exists a large fund of basic scientific knowledge, as a result of the advanced research of the past several years, which permits confidence that the technology required for manned lunar flight can be successfully developed. It would be misleading to imply that all of the major problems are now clearly foreseen; however, there is an acute awareness of the magnitude of the problems. The present state of knowledge is such that no invention or breakthrough is believed to be required to insure the over-all feasibility of safe manned lunar flight.

An aggressive research program which will insure a sound technological foundation for lunar vehicle system development is currently under way. This research is being carried out as a major part of the programs of the NASA Research Centers and in the supporting research activities of the NASA Space Flight Centers, both internally and by contract. It includes basic research in the physical and biological sciences; and applied research leading to the development of spacecraft, orbital operations, operations at the lunar surface, propulsion and [6] launch vehicles. This research is supported by a wide variety of experimental facilities in being, and new highly advanced facilities that are becoming available.

Consider, for example, one of the major spacecraft problems, that of aerodynamic heating. A lunar spacecraft will reenter the earth's atmosphere at about one and one-half times the reentry speed of a near-earth satellite and with twice the kinetic energy. Research to date has shown that radiative heat of the spacecraft by the hot incandescent gas envelope may become an appreciable percentage of the total heating. For the case of the reentering satellites, this radiative heat transfer had been unimportant. Analytical work and early experimental results have enabled estimates to be made of the gross radiative heat transfer. Continuing experimental research will be carried out in newer, more advanced facilities that are becoming available. Selected flight experiments to progressively higher speeds are needed for verification of the analytical and experimental results. The earliest of these, providing reentry velocities of 30,000 ft/sec, are scheduled for early 1962. All of this research will help to achieve detailed understanding of the heating problem, to allow accurate prediction of the heat [7] transfer, and to find the best materials and methods for spacecraft construction.

Research in this area, as well as in the other areas listed in Figure 3 [not provided], seeks to provide the basic information which should lead to greater simplification and reliability, and to reduced weight. The scope of the work is such that the basic information required in support of a manned lunar landing project should be in hand within three to five years.

LAUNCH VEHICLE DEVELOPMENT

The magnitude of a step in our space flight program, at any given time, will always depend on the capability of our launch vehicles. This capability, both present and projected, is shown in Figure 4 [not provided], where the payload weight at escape velocity is plotted as a function of time. During the current year, we should achieve the possibility of propelling 750 pounds to escape velocity, using the Atlas-Agena vehicle. By 1963, the Atlas-Centaur should increase this capability to 2,500 pounds; this will be doubled when the Saturn C-l becomes operational in 1964. However, the C-l is only an interim vehicle that is severely limited because of the lack of a sufficiently large high-energy [8] engine for the second stage. A later version of the Saturn, called the C-2, will more than triple the C-l payload capability at escape velocity. Because the second stage of the C-2 must await the development of the J-2 (200,000 pound thrust hydrogen-oxygen) engine, it will not be operational until 1967. The Saturn C-2 will be the first launch vehicle giving us the capability of manned flight to the vicinity of the moon; however, a single C-2 cannot provide sufficient energy to complete a manned lunar landing mission.

The required launch vehicle capability can be achieved in several ways. Two promising means are: one, orbital operations, wherein a number of Saturn C-2 launched payloads are rendezvoused, assembled or refueled in earth orbit, and then launched as a single system from earth toward the moon; and two, the direct approach, using a vehicle much larger than Saturn which would have the capability of propelling a sufficiently large payload toward the moon from the surface of the earth. Both methods appear to be technically feasible, and will be discussed.

Orbital operation techniques must be developed as part of the space program, whether or not the manned lunar landing mission is considered. These techniques will be required for [9] resupply and transfer to space stations and orbiting laboratories, for inspections and repair of other satellites, for rescue operations and for military applications. Successful development of these techniques of rendezvous, refueling and launching from orbit could allow us to develop a capability for the manned lunar mission in less time than by any other means. In view of these facts, NASA is planning a vigorous program for developing orbital operations techniques. This program is outlined in Figure 5.

Under present plans, initial rendezvousing, docking and refueling tests would make use of the Atlas-Agena vehicle. In these tests, conventional storable propellants will be used. In order to demonstrate the feasibility of orbital operations with high-energy hydrogen-oxygen propellants, a refueling exercise is planned wherein an Atlas-Centaur will be used to refuel an upper stage of a Saturn C-l vehicle. This demonstration is expected to be attempted in 1965 or 1966. Following this demonstration, full-scale refueling and orbital launch operations will be conducted using Saturn C-2 vehicles. These operations will involve the launch of several C-2's to refuel an upper stage initially put into orbit. Following the development of this capability in the 1967-68 time period, this system is [10] expected to be available for operational use in 1968-69 time period.

For the purpose of the manned lunar mission, the Saturn C-2 would be used to place into earth orbit an empty upper vehicle stage that would subsequently be used to propel the spacecraft toward the moon. Four or five additional C-2 payloads would be required to fill this empty stage with propellants. The last launching would propel the manned spacecraft together with the lunar take-off stage into earth orbit. Six or seven successful Saturn launchings, therefore, are required in order to place a space vehicle system into earth orbit that will then be capable of propelling an 8,000 pound spacecraft toward the moon, landing on the moon and returning it toward earth.

Orbital operations techniques will probably be required to perform the more difficult planetary mission even with the availability of much larger launch vehicles. Many of the missions shown in Figure 1 indicate the need for vehicles larger than the Saturn C-2. Large earth space stations that may be assembled in orbit will very likely require the launching of larger sub-assemblies into orbit than can be carried with a single Saturn C-2. Exploration of the moon following the initial landing will [11] also require vehicles larger than the Saturn C-2. Also, if the spacecraft weight increases materially as a result of information gained in the areas of weightlessness and radiation, the required number of earth launchings using Saturn could increase to an extent where the orbital operations techniques with this vehicle would no longer be attractive.

It is proposed, therefore, that a vehicle larger than the Saturn C-2 be phased into the launch vehicle program in an orderly fashion following the Saturn development. Such a launch vehicle, called Nova, would use a cluster of 1,500,000 pound thrust F-l engines in its booster stage. The exact number of F-l engines will have to be determined later, when a more complete definition of Nova missions is in hand. Nova might be sufficiently large to permit a manned lunar landing with a single launching directly from earth. Or, although substantially larger than the Saturn C-2, it might still not be large enough to approach the moon directly from earth; in this case it would materially reduce the number of rendezvous operations needed in earth orbit for each lunar mission.

A Nova-class vehicle development program, based on an assumed configuration, is given in Figure 6 [not provided]. The program is phased so that major decisions concerning the vehicle size and [12] configuration need not be made until after sufficient background information is available in the spacecraft development program.

The present program for development of the F-l engine is shown in this figure. Preliminary flight rating tests are now scheduled toward the end of 1963, and further testing should lead to a qualified engine by the end of 1965. Studies are under way to determine possible configurations of the vehicle and its performance capabilities. Preliminary design of the vehicle can be started in 1962 and would continue through 1963. As will be shown later, the spacecraft weight for the manned lunar mission should be firmly established in this time period.

Construction of static test stands and launch facility will be initiated in 1963. Developmental flight tests of the first stage could begin in 1966. Subsequent tests would add various upper stages until a complete launch vehicle should be ready for operational use in 1970.

Comparison of Launch Vehicles

A comparison of the Saturn C-2 and several Nova-class vehicles, as used for the manned lunar mission, is made in Figure 7[not provided]. The numbers under each launch vehicle indicate the [13] successful launchings required for each lunar flight. Spacecraft weights from 8,000 to 16,000 pounds are assumed; corresponding weights that must be propelled to escape velocity are indicated. Uncertainties in these latter weights are a result of uncertainties in the design of the lunar landing and take-off stages. In all cases, the use of storable propellants has been assumed for the return propulsion.

Use of the Saturn C-2 requires minimum of six to seven vehicles successfully completing each orbital operation. Increased spacecraft weight, failures of the launch vehicle, failures in the orbital operations, propellant losses either during transfer or by evaporation during the operation, and extra propulsion for accomplishing the rendezvous would all increase the required number of Saturns.

At this time, operations with six or seven Saturns appear to be feasible. However, if several of the aforementioned eventualities materialize, and if the number of launchings increases appreciably, the orbital operations technique for manned lunar landings may no longer be practical. A better definition of these problems will come during the orbital operations development program and during the spacecraft development program. [14] If, as a result of these programs, it appears that orbital operations are indeed feasible, the Nova development could be slowed down and delayed. Conversely, if the orbital operations become too complex and cumbersome, this work should be de-emphasized and the Nova development could be speeded up.

Use of the Nova-class vehicle offers the possibility of greatly reducing the required number of launchings from earth. It might be possible to provide mission capability without rendezvous with a four-engine Nova; with an eight-engine Nova, this type of mission capability is virtually assured.

Thus, if future difficulties force the use of an unacceptably large number of Saturns for this mission, the availability of a Nova-class vehicle would permit accomplishment of the planned flights. It should be recognized, however, that the development of Nova will undoubtedly bring about many problems, and will not be easy.

It is possible that other propulsion developments could contribute to manned lunar flight capability. Examples are the use of large solid propellant rockets, or nuclear propulsion. In defining a Nova configuration, consideration will be given to both of these types of propulsion. At the present time it [15] appears that nuclear propulsion will not be sufficiently developed for the initial manned lunar landing; however, nuclear propulsion might be very desirable and economically attractive for later exploration of the moon.

Programs in Support of Launch Vehicle Development

Activities presently under way or planned in support of the launch vehicle development are shown in Figure 8 [not provided]. For comparative purposes, major milestones for both the orbital operations and the Nova development are indicated.

Engine Development: The chemical fuel engines currently under development include the F-l, the J-2, and the LR-119. The F-l engine produces 1,500,000 pounds of thrust using conventional LOX/RP propellants; the J-2 engine will produce 200,000 pounds of thrust using hydrogen-oxygen propellants; the LR-119 produces a thrust of 17,500 pounds and also uses hydrogen-oxygen propellant. Both the LR-119 and the J-2 engine are scheduled for use in the Saturn C-2 vehicle. All three engines could be used in the Nova launch vehicle. The end of each bar in Figure 8 indicates the time when a qualified engine could be available. Also indicated in the figure is a proposed plan for testing a cluster of F-l engines; cluster testing could be completed [16] during 1966, if test facilities can be made available in time. Nuclear propulsion is currently under development jointly by NASA and the AEC. Although actively under development, the research character of this program precludes the possibility of determining schedules for manned use of this engine at the present time.

The feasibility of using large solid rocket motors in the first stages of launch vehicles of the Nova-class is also being studied. Test firings of rocket motors in the one-quarter to one-half million pound thrust class are planned for the 1961-62 time period.

These firings will be made with segmented motors that could be assembled to provide much larger capability.

Launch Vehicle Recovery: Means to reduce the high cost of launch vehicles are continually being sought. A promising method for possible major-reductions in hardware costs for future missions, is the recovery of launch vehicles. Launch vehicle recovery would also permit postflight inspection of hardware, offering the possibility of reducing vehicle development time and increasing vehicle reliability. Because of these possible advantages, a research and development program in the area of launch vehicle recovery will be implemented as indicated [17] in Figure 8. In this program, it is first planned to recover the booster stage of the Saturn C-2; later, recovery of stages from orbit will be attempted. If these methods prove to be successful, all of the launch vehicle hardware required for the orbital operations phase of this plan could be reused. Information gained during these operations could be applied later to the recovery of Nova vehicle hardware, thus offering the possibility of greatly reducing the cost of future operations.

Hawkeye Program: This country's first program making use of rendezvous techniques will be the Air Force's Hawkeye program. Much of the technology developed for Hawkeye might be applied to the proposed program of orbital launch vehicle operations. Close coordination with Hawkeye is, therefore, being maintained in order to derive the maximum benefits from this program.

SPACECRAFT DEVELOPMENT

The spacecraft development for the manned lunar landing mission will be an extension of the Apollo program. Before a spacecraft capable of manned circumlunar flight and lunar landing can be designed, a number of unknowns must be answered.

[18] The two most serious questions are:

1. What are the effects on man of prolonged exposure to weightlessness?
2. How may man best be protected from radiation in space?

The entire spacecraft design, its shape and its weight, will depend to a great extent on whether or not man can tolerate prolonged periods of weightlessness. And, if it is determined that he cannot, then the required amount of artificial gravity, or perhaps of other forms of sensory stimulation, will have to be specified.

The spacecraft design and weight will also be greatly affected by the amount of radiation shielding required to protect a man. In this area, a clear definition of the pertinent types of radiation, and their effects on living beings, is needed.

These two unknowns, radiation and weightlessness, might cause the largest foreseeable changes in spacecraft design. Other unknowns are also important, but will have lesser effects on the vehicle weight. For example, the lunar surface [19] characteristics must be defined before a landing system can be designed; yet it is not expected that any landing device will cause major weight perturbations.

As will be shown later, the complete answers to these questions will not be available for several years. It is proposed, therefore, to implement the Apollo spacecraft development in two phases. Apollo "A" will provide the capability of multimanned flight in earth orbit; it will also be a test vehicle, perhaps unmanned, for reentry at parabolic velocities. Apollo "B" will be an advanced version of Apollo "A" and will be phased into the development program at a later date, when definitive design decisions can be made. Apollo "B" will have the capability of manned circumlunar flight, and manned landing on the moon.

It is not suggested that the entire spacecraft development would be implemented in two phases. The Apollo spacecraft is conceived to employ a number of components, or modules, as listed in Figure 9 [not provided]. With the exception of the "command center," these modules will either be common to both Apollo "A" and Apollo "B" or they will be required for only one of the two types of mission.

[20]The command center will house the crew during the launch and reentry phases of flight; it will also serve as the flight control center for the remainder of the mission. It will be the only spacecraft unit designed with

reentry and recovery capability. Apollo "A" used in conjunction with the Saturn C-1 launch vehicle, will provide the capability of multimanned flight in earth orbit for extended periods of time. It will perform missions beyond the capability of Mercury, with increased sophistication and flight duration, leading to more definitive results concerning manned space flight; and it will provide for continuity in the manned flight program.

Apollo "B," used in conjunction with Saturn C-2, will be an advanced version of Apollo "A" with the capability of manned flight to the moon. It is conceivable that only minor changes in design, together with some improvements of onboard systems, will be desirable or required to modify the Apollo "A" spacecraft for the Apollo "B" mission. On the other hand, it is also possible that future knowledge will dictate a major change from Apollo "A" to Apollo "B."

Proposed development schedules for both the "A" and "B" command center units are shown in Figure 9. Also shown in this figure are the schedules for the design, fabrication [21] and flight testing of two types of onboard propulsion system. The Launch Escape Propulsion System will be used in case of a launch vehicle malfunction in the earth's atmosphere. The Mission Abort Propulsion System will provide return-to-earth capability for the remainder of the mission; it will also provide for maneuverability and course corrections; and, for a lunar landing mission, it will be used as the take-off stage from the moon. These propulsion systems will be used in conjunction with both the "A" and "B" command center units. Both propulsion systems will have to be thoroughly tested and highly reliable. The use of existing engines, such as the Agena engine, for the Mission Abort Propulsion System, appears to be very desirable.

The two remaining modules are the Orbital Space Laboratory and the Lunar Landing System. The Orbital Space Laboratory, to be used initially with Apollo "A," will be used for spacecraft evaluation, for crew training and for the development of operational techniques; it can also serve as a base for scientific measurements and technological developments. The Lunar Landing System will be used only with the Apollo "B" command center; controlled by this command center, the landing module will provide for a manned landing on the moon's surface.

[22] The schedules (Figure 9) for the design, fabrication and flight testing of each module of the Apollo vehicle were developed so as to be consistent with the availability of the required background knowledge.

Spacecraft - Launch Vehicle Phasing

The proposed schedule of spacecraft flights is compared with launch vehicle availability in Figure 10 [not provided]. The first manned flights on Saturn C-l with the Apollo "A" spacecraft will come a reasonable period of time after this launch vehicle is operational; orbital laboratory flights on C-l are not scheduled until after two years of operational use of this vehicle have elapsed. First manned flights on Saturn C-2 will be made with the Apollo "B" spacecraft, shortly after the C-2 vehicle is operational.

The first lunar landing, using the orbital operations approach, could occur at the time this approach is developed. Manned flights using Nova could take place not much later, if it is determined that the mission should be performed with the Nova vehicle.

[23]

Support by Unmanned Spacecraft Program

A significant amount of the information required in the design of the manned lunar spacecraft will be derived from unmanned space flight programs. These programs will yield scientific data needed to develop design criteria; and technological advancements that might apply directly to the manned spacecraft.

Some of the areas of interest are listed in Figure 11 [not provided]. At the top of this figure, significant milestones in the Apollo "B" development, and in the lunar landing system development, are given. Under these milestones, pertinent areas where information is needed are shown. These include: Information concerning the cislunar and lunar environment, where the several types of radiation will be probed, fields will be measured and meteorite impact probabilities will be assessed; the measurement of lunar surface properties, including terrain texture and features, surface composition, and physical characteristics; and the determination of lunar body properties, such as shape and mass distribution. Technological developments include power systems, tracking and telecommunications, attitude orientation and stabilization, mid-course and terminal guidance and control, retropropulsion, and impact absorbers.

[24] Of all of the areas mentioned above, the information pertaining to cislunar and lunar environment, and to lunar surface characteristics, is the most important. A clear understanding of trapped, cosmic, and solar flare radiation is required before the spacecraft weight can be fully determined. For example, reliable solar flare prediction methods would be required to support a decision that shielding against this type of radiation is not required. Of, if such prediction methods should turn out to be less reliable than is currently anticipated, further information on the directionality of solar proton beams would be helpful. Questions such as: "Do solar flare particles impinge on the dark side of the moon, or in the shadow of a crater?" must be answered. Detailed knowledge about the lunar surface characteristics is required before the design for the lading gear of the manned vehicle can be finalized, and before the exact method of touchdown on the moon (i.e., vertical or horizontal) can be determined.

A detailed analysis of the information presented in Figure 11 has shown that flights are scheduled in ongoing NASA programs which could obtain all the required information; and that this information is expected to be in hand prior to the time of hardware fabrication for either the Apollo "B" command center [25] unit, or the lunar landing system.

The earth satellite programs, using Scout, Delta, and the Atlas-Agena launch vehicles, will significantly increase our store of knowledge concerning the near-earth and cislunar environment. At least 26 firings of scientific satellites are planned between now and the end of 1964. In the same period of time, the Ranger spacecraft will probe the environment between earth and moon, and planetary probes of the Mariner series will obtain additional scientific information. In this time period, it might be desirable to schedule additional Ranger flights for the purpose of fully defining the environment in the vicinity of the moon, and on the moon's surface.

Both the Ranger and the Surveyor spacecraft will obtain information concerning lunar topography, surface characteristics, and body properties. According to present schedules, and assuming reasonable success, sufficient information will be available to design a lunar landing system for the manned spacecraft at the time when such information is required.

The Prospector series of flights will provide final landing system design confirmation. It will also assist in selecting the landing site for the manned craft, and might even [26] bring equipment to the moon's surface that could be used in the manned mission. Close coordination between the Prospector and Apollo projects will be maintained in order to assure maximum utilization of developments; such coordination should greatly benefit both projects.

Advancements in spacecraft technology will be derived from the earth satellite programs, and from the Ranger, Surveyor, and Prospector developments. Some of these advancements will apply directly to the manned lunar landing program.

Weightlessness and Radiation-Biological Tests

Before the Apollo "B" spacecraft design can be completed, the question previously raised concerning weightlessness must be answered. In Figure 12 [not provided], programs that are now planned in this area are listed; for comparison, significant milestones in the Apollo "B" development are also shown.

To date, manned weightless flights have been made for a [27] maximum time duration of one minute.[1] In this short time period, no gross physiological effects were noted. Ongoing programs will soon provide information of the effects of weightlessness on man for several minutes, and then several hours; and the effects on animals for many hours and then for several days. If, in each succeeding step, it is demonstrated that there are no adverse biological effects of weightlessness, then the design of a spacecraft without provision for artificial gravity can proceed with confidence; conversely, if future experiments show marked psychological or physiological changes as a result of prolonged exposure to weightlessness, then artificial gravity will have to be incorporated into the Apollo "B" spacecraft design.

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[1] Animals have been subjected to several days of weightless flight in Russian experiments. Although there are indications that these animals suffered no adverse effects, insufficient data are available, in this country, to draw any firm conclusions.

[28] As indicated in Figure 12, a considerable amount of experimental evidence on this subject will have been obtained before the Apollo "B" design is even started; complete information should be available before fabrication of hardware is begun. These conclusions, however, are based on the assumption that all programs that are currently in the planning stage, including the biomedical orbiting satellite program using Mercury capsules, will actually be implemented.

The biological effects of radiation in space will be determined largely from a correlation of the physical measurements previously discussed (Figure 11) with the results of ground measurements on biological specimen. However, a number of selected experiments in space, involving living subjects, will have to be made before shielding requirements for Apollo "B" can be fully defined. Tests of this type that either have been made, or are firmly planned, are indicated in Figure 12. Additional tests are currently being planned by NASA, in cooperation with the Air Force and the Atomic Energy Commission.

Manned Flight Technology

Much of the information required for the design of a spacecraft for manned lunar landing will be derived directly from Project Mercury, and from DynaSoar developments.

[29]The experience gained in developing systems for manned flight in space, and in preparing both the equipment and the men for such flights, will be of major importance. Operational concepts being worked out and applied in Project Mercury and DynaSoar should apply directly to future manned missions.

For example, the Mercury spacecraft will have all the onboard systems - the attitude stabilization and control system, the communications system, the environmental control system, etc. - that will be required in future manned spacecraft. Although some of the systems required for the Apollo spacecraft will be entirely new, their design should, in general, be related to Mercury experience; it is more than likely that many of the systems will be direct growth versions of Mercury equipment.

Extensions of Project Mercury, beyond the present program, are planned as part of the Apollo development. These flights would provide for extended periods of weightlessness, and perhaps for experiments with artificial gravity. Manned rendezvous tests, using the Mercury spacecraft for control, and a version of the Hawkeye vehicle as the controlled craft, can be carried out. The Mercury capsule cap also be used as a test bed for the development of Apollo guidance and control equipment. All of these flights can occur before manned flights with Apollo "A" are scheduled to take place.

[30] SCHEDULES AND COSTS

A summary of manned space flight missions, leading toward a manned lunar landing, is presented in Figure 13 [not provided]. Starting late in 1961, the Mercury-Atlas combination will give us the capability of orbiting one man for a short period of time. The Apollo "A" spacecraft, using the Saturn C-l launch vehicle, will allow multimanned, long duration, orbital flight in 1965. Later, in 1967, an advanced version of the Apollo spacecraft (Apollo "B") launched by the Saturn C-2, will provide the capability for manned circumlunar flight, and for lunar orbits.

Manned landings on the moon, using the Apollo "B" spacecraft, could be made in the 1968-1971 time period. If orbital operations using the Saturn C-2 vehicles prove to be practicable for this mission, then it might be accomplished toward the beginning of this range of time. On the other hand, if the spacecraft becomes much more complex than now envisioned, and consequently much heavier, a Nova vehicle will most likely be required before man can be landed on the moon. In the latter event, the program goals may not be accomplished as quickly.

[31]The plan presented in this report consists of a number of relatively independent programs. Decisions to implement these programs can be made

as time progresses; no single decision committing NASA to carry out the entire plan is required at this time. The plan is also sufficiently flexible to permit major changes in objectives in later years, without the requirement that earlier phases of the program be repeated.

Some of the major phases of the Launch Vehicle Program are shown in Figure 14 [not provided]. For each of these phases, the year of initiation is shown, together with the total duration of this phase and total funding required to complete the phase. Thus, for example, a decision to go ahead with the Atlas-Agena docking demonstration would be required in FY 1962, in order to meet the total program objectives; the total funding required for these tests would be $80,000,000 distributed over a period of nearly three years.

In the Nova development, only those phases that are not now funded are included in Figure 14. Thus, it is assumed that the F-l engine development, and the Nova configuration [32] studies that are presently under way, will be continued. No major new commitment will be required until late in FY 1963, when the development of the first stage would be started.

A similar breakdown for the phasing of various components of the spacecraft is given in Figure 15 [not provided]. In order to meet the previously presented program objectives, the development of the Apollo "A" spacecraft, the Launch Escape Propulsion System, and the Mission Abort Propulsion System, would have to be initiated in FY 1963. The development of the Orbital Laboratory, the Apollo "B" spacecraft, and the Lunar Landing System would follow in later years.

The aforementioned flexibility of programming also becomes evident in this figure. Assume that for some now unknown reason it becomes undesirable to explore the moon in the suggested time period, and that a decision is made that a large space station should be developed first. Such a decision could be made as late as 1965, without previously having committed anymore than the design phases of the manned lunar vehicles.

[33]A summary of the development and funding schedules is presented in Figure 16 [not provided], where the various program phases are given as a function of the fiscal year of program initiation. Most of the funds initially committed in 1962 will be for design phases. Major hardware contracts would not be awarded until 1963, with additional hardware developments starting in 1964 and 1965. The average cost per year, over a ten year period, for the total program is of the order of $700,000,000.

A basic ground rule in developing this plan was that the funding for fiscal year 1962 cannot be increased beyond the level that has been submitted to the Congress. However, increased funding in fiscal year 1962, in selected areas, might give increased assurance of meeting the projected flight dates. In particular, acceleration of the Saturn C-2, through earlier funding of the S-2 stage, would make this vehicle operational as much as a year before it is required for manned flight; the present program does not provide for any time between launch vehicle availability and manned spacecraft flights.

Earlier C-2 availability, together with earlier funding for the orbital docking demonstrations, would allow for additional unmanned orbital operations before manned flights [34] to the moon are made. Earlier spacecraft funding, for Apollo "A, "would lead to earlier flights with this vehicle. In the area of life sciences, increased funding in fiscal year 1962 would lead to the earlier availability of information on the effects of prolonged periods of weightlessness, and the biological effects of radiation.

An examination of the required NASA staffing to carry out this plan was not made as a part of this study. However, it must be recognized that neither Marshall Space Flight Center nor Space Task Group, as presently staffed, could fully support these programs. If the program is to be adopted, immediate consideration must be given to this problem.

CONCLUDING REMARKS

In, preparing this plan for a manned lunar landing capability, it was recognized that many foreseeable problems will require solutions before the plan can be fully implemented. Yet, an examination of ongoing NASA programs, in the areas of advanced research, life sciences, spacecraft development, and engine and launch vehicle development, has shown that solutions [35] to all of these problems should be available in the required period of time.

Throughout the plan, allowances were made for foreseeable problems; but it must be recognized that unforeseeable problems might delay the accomplishment of this mission. Nevertheless, the plan is believed to be sound in that it requires, at each point in time, a minimum committment [*sic*] of funds and resources until the needed background information is in hand. Thus, the plan does not represent a "crash" program, but rather it represents a vigorous development of technology. The program objectives might be met earlier with higher initial funding, and with some calculated risks.

[pp. 36- 51 not provided]