LUNAR ORBITAL RENDEZVOUS FOR APOLLO

Based Upon and Excerpted From a Speech by

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In view of the recent NASA decision to use the lunar orbital rendezvous approach as the method for accomplishing the first manned landing on the moon and subsequent return to earth, it would seem advisable at this time to review the technical considerations which led to our selection of the lunar orbital rendezvous mode (LOR) and to describe briefly the mission profile.

When the Program Office of Manned Space Flight was established in the Fall of 1961, one of the very first problems to which we turned our attention was the selection of a mission mode. It is true that a primary mode, earth orbital rendezvous (EOR), had been tentatively selected, with a direct mission backup capability in the program. Fortunately, the development work that has been done since then could be handled in such a way as to be consistent not only with this tentative selection, but also with any of the other modes under consideration. However, a firm decision obviously became more and more important with the passing months.

We recognized this need to reaffirm the EOR mode, or select another as quickly as possible, as soon as the Office of Manned Space Flight was established. We also knew, however, that it was absolutely essential to go back and examine in great depth each possibility. We therefore assigned this as a priority task to our Office of Systems.

The ensuing study has since occupied a great deal of time and effort in the Office of Manned Space Flight, as well as at the Marshall Space Flight Center in Huntsville and the Manned

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Spacecraft Center in Houston. Other governmental activities, and a number of industrial concerns, also have contributed time, money, and brainpower. The three proposed Apollo modes which were finally considered in detail were: the direct flight mode, using the Nova launch vehicle; the earth orbital rendezvous mode, requiring separate Saturn launches of a tanker and a manned spacecraft; and the lunar orbital rendezvous mode, requiring Saturn launch of the manned spacecraft and the lunar excursion module.

In the direct flight mode, a three-stage launch vehicle would place a 150,000-lb spacecraft into a $2\frac{1}{2}$-day earth-to-moon trajectory from which the spacecraft would deboost to a lunar orbit for descent to the lunar surface with a touchdown weight of approximately 50,000 lb. On completion of the lunar stay, the return spacecraft would be launched for injection into a moon-to-earth trajectory designed to permit re-entry of the command module such that landing would occur at a preselected point on the earth's surface.

The earth orbital rendezvous, or EOR, mode was studied in several versions. It was evident fairly quickly that a connecting mode, in which the spacecraft and a fueled escape vehicle would be put separately into orbit and then joined, could not be accomplished with a logical split in payload because of the weight of the injection stage. The second alternative, the tanking mode, differed from the direct flight mode principally in its concept of fueling the injection stage while in earth orbit. This maneuver would require rendezvous in earth orbit between an unmanned tanker and a manned Apollo spacecraft, including an unfueled injection stage. Thus the lift-off weight of the manned spacecraft would be reduced by several thousand pounds of cryogenic fuel. After the refueling operation, the injected weight of the manned spacecraft could be the same as for the direct flight mode. Using this mode, the mission could be accomplished with a Saturn-class three-stage launch vehicle, thus avoiding the delays incident to the development of a larger Nova launch vehicle required for the direct flight mode.

In the LOR mode, the injected spacecraft weight would be reduced from 150,000 lb to approximately 80,000 lb by eliminating the requirement for the propulsion needed to soft-land the entire spacecraft on the lunar surface. A small lunar excursion module, or LEM, sometimes referred to as the "Bug," would be detached after deboost into lunar orbit. The Bug would carry two of the three-man Apollo crew to a soft landing on the moon and subsequently would be launched from the moon to rendezvous with the third crew member in the "mother ship."

The entire crew would then return to earth aboard the command module in a manner similar to that described for the direct flight mode.

The choice between these three contenders was not an easy one, nor lightly taken. Each offered substantial benefits which were thoroughly analyzed and carefully weighed. We concluded that LOR offered the greatest assurance of successful accomplishment of the Apollo objectives at the earliest practicable date. In reaching this decision, we studied all available facts, and received the considered judgments of many interested groups.

To provide the basis for final selection, we compared the three modes (including five variations of the direct flight mode) in as much detail as our current knowledge of component and subsystem performance would permit. We considered a substantial number of launch vehicle and spacecraft combinations representing a spread of injected spacecraft weights ranging from about 60,000 to 240,000 lb. The launch vehicles considered were: a) the Saturn C-5, both with and without engine-out capability and with either two or three burns to orbit; b) the Saturn C-8 with similar variations in pre-injection profile; c) the liquid Nova launch vehicle; and d) the solid Nova.

Spacecraft in-flight propulsion systems considered included various combinations of hypergolic and cryogenic fueled stages, both pump-fed and pressure-fed, to provide the required propulsion for midcourse correction maneuvers, deboost to lunar orbit, descent to and launch from the lunar surface, and escape from the lunar parking orbit for return to earth.

Feasible combinations from this matrix of launch vehicles and spacecraft, supplemented by required systems for guidance, control, communications, tracking, abort operations, and life support, were measured against carefully selected criteria which had evolved from our experience to date and from our analysis of as-yet-unknown factors which might influence the choice. The following order of mode comparison criteria is not necessarily indicative of the importance of the criteria discussed.

The capability of each of the three modes for accomplishing the Apollo mission was analyzed, including consideration of the number of men to be placed on the moon, the length of their stay, and the scope and extent of possible lunar surface operations. Under this criterion, EOR and direct flight modes have a slight edge, although there is little difference in the capability of any of the modes to accomplish the gross mission objectives -- to land United States astronauts on the moon and return them safely to earth.

Careful analysis was made of the performance margins offered by each of the modes as currently conceived. This was primarily an analysis of the capability of the proposed propulsion systems to accommodate the conceivable increase in component and system weights as development and testing proceeded. EOR offers the least performance margin, with LOR and direct flight following in that order. This analysis, of course, was quite sensitive to our present ability to estimate component weights, which vary widely at this stage of system design.

The guidance accuracy required of each of the three modes was compared with the general conclusion that presently foreseen technology readily can meet the stringent accuracy requirements of EOR for its earth orbital operations and LOR for its lunar orbital operations. Direct flight requires less precision, and therefore guidance systems for the direct flight mode would be the simplest.

The communications and tracking requirements were analyzed with a similar conclusion that the direct flight requirements were the simplest to meet, but that communications and tracking for both EOR and LOR are well within projected ground operational support systems capabilities.

The development complexity associated with each of the modes was carefully weighed. EOR requires development of the tanker system, LOX transfer techniques, operation of cryogenic stages in space, rendezvous between manned and unmanned spacecraft, and development of a large lunar touchdown module. LOR uniquely requires the development of rendezvous techniques in lunar orbit, and the development of an additional manned spacecraft, both light in weight and with adequate protection from environmental hazards such as solar radiation and micrometeorite flux. The direct mode requires major launch vehicle development, as well as the use of a cryogenic stage in space, and the large lunar touchdown vehicle as indicated for EOR. The LOR mode appears to offer a sizable advantage under the criterion of development complexity for the overall system.

A major selection criterion was the probability of mission success, and mission safety. This analysis required a detailed assessment of the reliability of each subsystem as well as of the overall system at each step along the mission profile. Although extremely important, it is obviously very difficult to predict reliability for the multiplicity of required subsystems in view of the paucity of statistical data. It is impossible, therefore, to place much credence in the absolute values resulting from such a numbers game, but the relative ratings of the various modes can be assessed. Contrary to most instinctive first impressions, we found that the mission success probability of LOR and direct flight were approximately the same. EOR has only two-thirds the probability of the other modes because of the requirement for multiple C-5 launches. The mission safety probability for all modes was nearly equal, the rendezvous requirements in LOR being roughly equivalent to the problem of landing a larger stage and using cryogenics in space as required for EOR and direct flight.

The overall mission schedule, both for systems development and operation was, of course, an important consideration. Using a conservative approach, we concluded that LOR can accomplish the lunar landing some months earlier than either EOR or direct flight.

Also of fundamental importance is a relative comparison of Apollo costs as predicted for each of the three modes. Again using conservative forecasts, it appears that costs of the three modes, from design through first successful mission, will be quite close, but that LOR costs will probably be some 10% less than for either EOR or direct ascent. This results primarily from the less expensive hardware developments involved, and because LOR will require fewer launch vehicles to accomplish the same amount of premission training.

Finally, we considered carefully the growth potential of each of the three modes. We concluded that each would probably require development of a lunar logistic vehicle for full exploitation of the moon's potential benefits. Each mode would result in significant advances in space technology for such areas as earth orbit operations, manned planetary programs, and military applications.

In summary, the schedule advantages, cost advantages, and developmental simplicity of LOR led to its selection as the prime mode. In other areas the technical factors considered did not dictate the selection of one mode over another.

The Apollo objective, using the LOR mode, is to land two of a three-man crew on the moon; sustain them there for at least one day (possibly up to seven) and return them, together with the third crew member, safely to earth. To accomplish this objective will require a spacecraft-booster configuration which will dwarf any we have seen to date. The three-stage Advanced Saturn booster will reach to a height of some 280 ft and will be topped by the spacecraft and ejection tower which reach an additional 75 ft above the booster. The total lift-off weight will be approximately 6 million lb, for which the Saturn S-1C first stage will provide $7\frac{1}{2}$ million lb of thrust from five F-1 engines. The S-II second stage will develop one million lb of thrust from five J-2 engines, and a single J-2 engine in the S-IVB stage will provide 200,000 lb of thrust to place the 80,000 lb spacecraft into the trajectory which will carry it to the moon.

The spacecraft itself will consist of three major elements: the Command, Service, and Lunar Excursion Modules which, respectively, will weigh approximately 10,000, 42,000, and 25,000 lb. The Command Module will carry the three-man crew together with guidance, communications, and life-support systems. The Service Module will contain propulsion systems for midcourse maneuvers as well as for deboost into, and escape from, lunar orbit. Finally, the Bug will carry two of the crew members to the surface of the moon, along with scientific instruments, communications and guidance systems, and propulsion required to return them to the orbiting Command Module.

We plan to launch the Apollo from Cape Canaveral into an inclined earth orbit. During the first revolution around the earth, the spacecraft will be injected into its earth-to-moon trajectory. In the first few minutes after injection, the Command and Service Modules will be reoriented to mate the Bug with the Command Module in a nose-to-nose manner. This can be done either by "flying" the Command Module to its reoriented position or by transferring the Bug by mechanical means. Further study will determine which alternative is best.

Approximately 45 min after injection, the first midcourse correction maneuver will be accomplished, using the Service Module propulsion system. The magnitude and direction of the midcourse maneuver will be determined by computer calculations, backed up by calculations from the crew and from the ground support systems, which will maintain communication with the spacecraft throughout the mission via the Deep Space Instrumentation Facilities (DSIF). A number of midcourse maneuvers may be required to place the spacecraft into position for deboost into a precise, circular lunar orbit approximately 100 nm above the lunar surface.

While the spacecraft is coasting in its predetermined lunar orbit, the crew will prepare the Bug for descent to the lunar surface. The two lunar explorers will transfer to the Bug through the hatch at the connection point between the two vehicles. The Bug will then be separated from the Command and Service Modules, which will remain in lunar orbit.

The main engine of the Bug's landing stage will decelerate the vehicle. Then through a carefully blended combination of manual control and automatic system operation, the Bug will be lowered nearly to the surface, will hover, and, if necessary, move laterally so that the crew can select the touchdown point. They will be aided by maps, reconnaissance data, and, possibly, a previously landed beacon. At any time during descent the crew can return to the mother ship. It appears that the first landing should be made in the vicinity of the lunar equator and preferably on the leading edge of the moon's surface -- between 270° and 360° longitude. Descent to the surface is probably the most critical phase of the entire operation. Fortunately, the Bug will be small and will be designed specifically for landing, rather than for both landing and recovery.

Once on the moon, and before taking any other action, the two explorers will prepare for relaunching. In addition to their own inspection and checking, they will be instructed and guided in this activity by the third crew member in the mother ship and by information transmitted from earth. This done, the exploration phase of the mission will begin.

As presently conceived, the Bug will carry approximately 200 lb of equipment for scientific exploration and experiments during the crew's stay on the moon.

Photographs and surface samples will be obtained. Probably apparatus will be left on the moon for continued operation and transmission of scientific data back to earth.

When it becomes time to relaunch the Bug, the crew will fire the launching engine at a precisely determined instant while the mother ship is within line of sight. The Bug will enter a transfer ellipse calculated to rendezvous with the mother ship after traveling part of the way around the moon. The docking of the mother ship and the Bug, controlled by the crew of the Bug, will be a critical operation - it should be stressed here, however, that this maneuver can earlier be practiced extensively in earth orbit. After docking, the crew of the Bug will transfer back into the Command Module, and the Bug probably will be left in lunar orbit to save weight on the return trip.

After the Command and Service Modules are thoroughly checked out and all calculations are confirmed, the Apollo spacecraft will be fired into its return trajectory. After midcourse corrections, and just before entering the earth's atmosphere, the Service Module will be jettisoned, and the Command Module will be oriented for re-entry. At an altitude of approximately 50,000 ft a drogue parachute will deploy to stabilize the vehicle. This will be followed shortly by the main parachute system, which will lower the Command Module gently to earth -- probably on land rather than at sea.

The mission described here has been widely reported in the newspapers and technical journals, with a liberal use of superlatives in assessing its magnitude and complexity. In this case, resort to superlatives is well-advised -- this is truly a staggering undertaking. Entirely new concepts of component and system reliability must be developed and proven. Extensive tests must be carefully planned and conducted, and results must be exhaustively studied. Crew capabilities must be developed and meshed with proven automatic systems so that the two work together with Swiss-watch precision.

It is a challenging task, studded throughout with difficult decisions which must be soundly based and promptly made. The list of participants will be large, including scientists, engineers, administrators, industrial workers, aerospace medicine experts, and the astronauts themselves.

With the decision made as to the method by which we will go to the moon we think we have taken a giant step forward. Essentially, we have now "lifted off" and are on our way. Let me conclude, then, by reiterating a few of our basic concepts.

We believe it was necessary to evaluate carefully all feasible mission modes and select the best of these upon which to concentrate our efforts.

We believe that the lunar orbit rendezvous mode is best.

We believe that we must obtain the very best efforts of the very best people we can find, both in Government and industry, if we are to achieve our national goal.

We believe that our organizational concepts and management techniques must be no less excellent than our technical efforts.

We believe that with constant attention to these concepts, and with the hard work and dedication of the people involved, we will be able to carry out our responsibility to our country to be second to none in man's conquest of space.