ENGINEERING AND OPERATIONAL APPROACHES FOR PROJECTS GEMINI AND APOLLO

By
ELLIOT M. SEE, JR. (M)
NASA Manned Spacecraft Center

In assessing the status of Projects Gemini and Apollo today, it could be said that we are at an intermediate stage of development. The broad objectives and basic approaches have been established. However, the first manned flight of the Gemini program is still more than a year away, and the first Apollo manned flight at least several months after that. A great amount of engineering and operational development remains to be accomplished. It is my intention to review some of these areas of development and indicate the approaches being taken.

As a background for better understanding of these approaches, I would like to briefly review the mission plans for both projects.

Gemini is our next step in manned spaceflight. (Fig. #1) It retains the shape of the Mercury spacecraft but has two large modules attached to the base of the heat shield to provide additional capability in space. The first is the retrograde section which houses the retrorockets. The second is the equipment section which carries the fuel cells, cryogenic storage, and the OAMS thrusters for attitude and translation maneuvers in orbit. These sections are jettisoned prior to re-entry.

We will start the flight program within the next few months with unmanned flights to test the launch vehicle spacecraft interface, and all systems for life support and re-entry. Early manned flights will be for spacecraft systems checkout and increasing duration in orbit.

Our longest mission may be as many as 14 days in orbit. On these early flights we may also make some evaluation of rendezvous systems and techniques by use of a small rendezvous evaluation pod to be carried in the Gemini and jettisoned for this purpose.

Later Gemini flights will rendezvous with an unmanned Agena which is launched into 161 nautical miles circular orbit approximately 24 hours before Gemini launch.

For rendezvous, we have approximately a four and one half hour launch window daily. The Gemini will be launched into an 87-161 nautical mile elliptical orbit. There are several methods to put the two vehicles within working distance of each other. Direct ascent is ideal but launch timing is critical. Direct ascent with a yaw maneuver by the launch vehicle is a variation on this method but we are still studying the feasibility in terms of payload. The second method is catch-up. (Fig #2) Gemini can be launched when Agena is not overhead. By the nature of its lower elliptical orbit, Gemini can overtake the more slowly orbiting Agena. When Gemini reaches its apogee point it will then circularize its orbit by using the OAMS thrusters. Terminal phase of the rendezvous and subsequent docking will also be completed by the OAMS thrusters. If the Gemini is too far out of phase with Agena for a fast catch-up, the Agena engine will be fired to put it into a higher elliptical orbit permitting the Gemini to catch up sooner. (Fig #3) Final rendezvous would still be made in a 161 nautical mile circular orbit. In addition to the phase corrections just described, Gemini and Agena will have a limited capability for plane corrections in the rendezvous maneuver. (Fig. #4)

Although a single ringsail parachute similar to that used in Mercury will be utilized for recovery on the early flights, we plan to phase into a paraglider as the prime method of landing the spacecraft after re-entry.

For the Apollo mission, we will start with earth orbital flights to check out the Command and Service Modules launched by the Saturn One launch vehicle. With the more powerful Saturn One B launch vehicle, we will put the CSM and LEM into earth orbit for docking and systems development.

The Apollo lunar mission consists of 48 separate steps and will begin the three stage launch of a Saturn Five into an earth parking orbit. (Fig #5) Using onboard sightings and ground based radar tracking, this orbit will be defined and computer calculations made for the S-IVB stage injection into the trans-lunar trajectory. After injection and passage through the radiation belts, a free flight turn-around maneuver is performed to transposition the LEM to the nose of the command module and SIV-B is then jettisoned. This maneuver exposes the service module for mid-course maneuvers and permits the crew to enter the LEM for initial checkout. As a matter of interest, we now think it may be possible to complete this trajectory with as few as two mid-course maneuvers, one soon after injection and one at the other end of the trajectory.

As the spacecraft approaches the moon, the service module engine will retrofire to place it into an 80 nautical mile circular orbit around the moon. After precise definition of this orbit, two of the three crewmen will transfer into the LEM, and fire the descent engine to go into an equiperiod orbit with a pericynthion of about 50,000 feet. Final descent will be made from this altitude using the controllable thrust engine.

After the landing has been accomplished the crew will prepare for relaunch, then perform scientific exploration of the surface using a portable life-support system and suit designed for lunar surface conditions. Launch from the lunar surface will be made with the ascent stage of the LEM. When rendezvous and docking with the CSM is completed, the two men transfer back into the command module, the LEM is jettisoned in lunar orbit and the service module engine fired for injection into the trans-earth trajectory. Nearing the earth, the service module is jettisoned and re-entry made with the command module only, followed by a landing with a parachute recovery system.

Our progress on the Gemini and Apollo projects is not always smooth or easy. As with every research and development program, we have our problem areas and recognize them as such. Design decisions for the final spacecraft must be based on thorough engineering and continual testing. Sometimes it involves schedule slippages, and we try to be flexible here and reorient our mission planning as problems develop and are solved. Designing a system with a good fix is more important than designing one in a given time period that may not function reliably.

We are at a time period in Gemini when many of our problems are down to the unglamorous nuts and bolts engineering that must be done before the vehicle flies but which does not radically affect the mission plan.

In launch vehicle guidance, we have developed an innovation which gives us a back-up capability to conduct a successful mission. We have the option of using the primary guidance in the booster, and if it malfunctions in some way, we can switch over and use the secondary guidance in the spacecraft to continue the launch.

Originally we had no switchover capability between the two systems. But it was felt we needed the secondary switchover in the first missions and it looks so good we have planned it for all Gemini missions. Needless to say, this provision for using the spacecraft guidance during launch is very appealing to us in the pilot group.

Ejection seats have been selected as the crew escape system during powered flight instead of the launch escape rocket used in Mercury. In developing this system, we are designing it with an abort capability up to 70,000 feet as well as off the pad. It is not as difficult a problem as may seem since at the higher altitudes we have passed our max Q point with the launch vehicle. We are, however, considering a lowering of the altitude where we go to spacecraft mode abort instead of ejection seats. The limiting item here is retro rocket thrust sufficient to overcome the Q loads. We are able to make the seat for escape-rocket tradeoff in Gemini because of the nature of the launch vehicle. With the hypergolic fuels in the Titan booster, we have heat but no overpressure or explosion problem as in the Atlas. Dummy ejection tests to fully develop the system are still being conducted and are proceeding well. An innovation with this seat system will be the use of a ballute for stabilization after separation from the seat.

Fuel cells will be used in Gemini for the first time as a space power source, providing considerable weight savings on longer missions when compared to chemical batteries. The fuel cell operates on the reverse of the principle of electrolysis, combining hydrogen and oxygen in the gaseous state to produce electrical power and water.

The potability of this water is being tested chemically and with mice. Apparently it is all right, but I have heard that one of the mice became pregnant. A small problem with the fuel cell at present is purging methods for adequately cleaning water and inerts from the hydrogen side of the cells during operation. One solution being considered is an increased Δ P of the purging gas.

In the rendezvous radar system, we are looking at a problem of pulse rates. In the final closing maneuver, it appears that we may be blocking our own signals since the pulse returns even before we have finished sending it. We are studying the advantage of an automatic signal to rigidize the docking collar after contact.

In the paraglider development program, we have an entirely new concept on controlled landing for spacecraft. It has required, and will continue to require a careful development program. For instance, in selecting the material for the wing, we had to conduct a series of wind tunnel tests on all types of synthetic fibers to select the best material that could be stowed in a small area in the spacecraft. Testing narrowed the field to two different types, one of which has been selected as the prime material and the second as a back-up. We have learned that even the most innocuous type of thing can cause problems. For instance, we tested one material, and to make it look good, painted NASA in red letters on the wing. During the test, a rip developed in the wing right through the letters. We found out that the paint had interacted with the material and weakened it to the point of failure.

We are studying the possibility of adding a VHF radio to the Gemini communications system. Normally, we use UHF and HF on the spacecraft for communications. In case of a contingency landing outside the U. S., the VHF capability would be particularly valuable.

Another landing aid being considered after paraglider deployment is a direction finder, which could give us a fix on the preselected landing strips. But a direction finding antenna would pose a problem. We cannot have an externally fixed antenna since it could not survive re-entry and would certainly create other stability problems. A possible solution might be a retractable antenna with four-way electronic switching.

The capability to perform extravehicular tasks in space is an interesting aspect of the Gemini program. It would give us some possibility of extended scientific tasks. We already have the capability to open the hatch and have the astronaut stand up. The next logical step is to develop the means by which he can leave the vehicle. We are studying the use of a separate oxygen bottle and long electrical cable for extravehicular operations. I'm sure you are all aware that pressurized suit mobility will be a major problem to be faced in any operation of this type.

In Apollo, we have considerably different requirements for the space vehicle. The mission is more complex and for the first time will be performed mainly outside of earth orbit.

Vehicle stability is one major consideration that occupies a good deal of attention on the program now. When the Apollo is fully equipped the CG is closer to the apex than we would like. So if the Apollo makes a water landing, it could float apex down.

For ventilation and access, we need to keep one of the two hatches well above water. We are considering floatation aids on the command module which would deploy shortly before impact.

The aerodynamic trim presents another area of consideration. We have an offset CG in Apollo to provide natural trim at $L/D = 0.5$. This is used to maneuver the spacecraft to a preselected landing area within a footprint of about 800 by 4000 nautical miles. But at low speeds under abort conditions the longitudinal position of the CG gives the CM a trim point with the apex forward. Mercury had a destabilizing flap on the nose of the spacecraft to eliminate this trim point. On Apollo, we first added long aerodynamic fins called "strakes" in an attempt to eliminate the apex-forward trim point.

But tests proved that the strakes were not the solution to the problem because of excessive weight and dynamic stability considerations. We are now considering another method of eliminating the apex forward trim point. This method of destabilizing the command module consists of retaining the escape tower after the Launch Escape Rocket has been jettisoned. It is possible that the tower can eliminate the forward trim point at less weight penalty and greater dynamic stability than the strakes. The tower would then be jettisoned later in the sequence.

Impact problems differ from Gemini and Mercury. We plan for a ground landing with Apollo but do not have external landing gear like the Gemini spacecraft. The "landing gear" are essentially mounted under the astronaut's couch. Tests conducted with crushable honeycomb material indicate the stroke of this system is presently too short to absorb all the shock of a landing. Structural deformation is an additional method being considered for attenuation. The spacecraft will not land flat, but at an angle on the heat shield.

We have decided upon the lunar orbit rendezvous mode for the lunar mission, but there are many details of trajectories and landing which must be investigated thoroughly now to determine the exact mission plan.

We are basing our current planning on free-return trajectories, which give a transfer time of about 70 hours. This type trajectory will continue around the moon and return to the earth entry corridor with no guidance impulses required greater than the capability of the translation control system. The free-return trajectory has an obvious advantage in that it allows for a service propulsion system failure, but it does restrict us to landing areas near the lunar equator. A longer duration flight such as 90 or 95 hours would require less fuel since we could approach the moon at lower velocities, but this would not be a free-return trajectory. The use of the LEM engines as a back-up for the service propulsion engine is being studied, but poses many problems in dynamics of the combined vehicle, guidance, and operation.

We are considering several different LEM transfer orbits. The prime method we have adopted is equiperiod orbit. In this maneuver the LEM is released from the Command Module 90 degrees away from the preselected landing point. It is an excellent transfer orbit in case of abort but is the most expensive in fuel. The least expensive in fuel is of course the Hohmann transfer which releases the LEM 180 degrees from the landing point.

In the lunar landing maneuver, there are various areas under consideration. For flight and systems controls we are tailoring the trajectories and missions to permit crew participation in degraded modes. In this area, we are looking at several trajectories to select the one best suited for crew control and visibility. To give an example of the lunar landing trajectory in a familiar area, I have shown the final descent for a landing at Edwards AFB. (Fig #7) For this descent, the equiperiod transfer orbit would have started 1700 miles east, about the vicinity of Birmingham, Alabama. The final descent would start at 50,000 ft. over the Colorado River and speed would be almost Mach 6. Descent would have reached 10,000 ft. and speed would be about .8 Mach no. passing Boron eight miles from touchdown. At this point the LEM engine would be throttled down and the spacecraft rotated for better visibility. After reaching 1,000 ft. at Edwards, final touchdown must be made within two minutes.

Although much is unknown about the lunar surface, we have written specifications for the LEM landing gear. It must be capable of landing on an 11 degree slope and retain the capability to relaunch immediately. It must be able to land at 10 feet per second vertical velocity and 5 feet per second horizontal velocity. It must have a bearing strength of 12 psi under a dynamic load and for effective protuberances two feet above the surface. But we must also attempt to identify the surface on which we will land. To make a safe landing we need information on the texture of the surface, including local relief, protuberances, and depressions. We also need to know slope gradients. The surface structural properties is another vital area with the bearing strength, dust depth layer, and hidden protuberances in the dust as major factors.

Our Ranger and Surveyor unmanned lunar landers will attempt to answer some of these questions soon. Ranger is essentially a hard lander designed to get close-up pictures of the surface. Surveyor is a soft lander to obtain soil samples and ground level pictures of the terrain. The Surveyor orbiter will orbit the moon and map the lunar surface. It will also measure such environmental conditions as the magnetic field and micrometeroid particles near the moon. These programs will be major factors in defining the surface we are going to land on.

We must also design for a "crash" condition when it is clear that thrust must be terminated prior to touchdown. We must minimize the hazard as much as possible and are looking into the crushability of the landing engine skirt and associated plumbing at the present time. We must also have an abort capability after landing. The ascent stage must not be damaged and a clear separation must be possible. "Fire in the Hole" with damaged descent structure imbedded in the lunar surface is under investigation at the present time.

The natural environment in which we will land must be studied not only in regard to surface condition but also in regard to meteoroids, radiation, and lighting. The less we know about the environment, the more penalties we have in the mission plan and total weight of the spacecraft. For instance, if we can more clearly define the frequency and penetrotion of meteoroids and the amount and type of shielding needed for radiation hazards, the design can be made and developed to less conservative criteria.

In this respect, lighting plays a part not only in the landing area, but in thermal considerations. (Fig #8) An earthshine landing may be advantageous in reducing the amount of environmental support needed in the spacecraft. It also changes the operating parameters for onboard equipment. But lack of atmosphere on the moon may make an earthshine landing difficult. Light will not be refracted and the photometric property of the lunor surface has a rather pronounced effect on observed brightness. (Fig #9) This property will produce a so-called "halo effect" whereby each observer will see a brighter ring of light oround his shadow, but not around others.

The docking interface for Apollo is a subject of much interest in the project at present. Mechanical docking devices which clamp two sections together are the conventional method of approach, but on a lunar mission they add unnecessary weight to the system. A lightweight docking device which can be extended from the command module, secured, and then draw the two vehicles gently together, is under consideration as an alternate method of achieving final docking.

I hope this discussion of some of the engineering and operational approaches in Gemini and Apollo has given you an idea of the current efforts in these projects. Although our flight operations are in a rather quiet period right now, there is an extensive program of research, design, and testing being conducted at the various NASA centers and by our contractors all over the country.

I thought it would be interesting to include a brief description of the spacecraft design principles which we in the astronaut group find ourselves stressing at the engineering meetings we attend.

Although the spacecraft and systems we deal with are different from aircraft in many ways, I wos pleasantly surprised to realize that these were the same principles test pilots have been stressing for years.

ONBOARD COMMAND should be primary.

VISIBILITY should be given a high priority.

MANUAL SYSTEMS OPERATION should be provided except when automatic systems are necessary for time-critical functions or when they can relieve the pilot from routine controlling. The latter category should have a capability for manual backup operation.

FLEXIBILITY should be provided in spacecraft systems and operational modes.

SIMPLICITY with adequate accuracy should be preferred over complexity with better accuracy.

STANDARDIZATION should be utilized because of its value in crew training.

In closing, I would like to share with you a few thoughts on the reasons for the space program. There have been many reasons advanced, most of which have considerable merit. I personally think of it as a major research and development program which can be of immense benefit to our country in the long run. Examples of previous scientific research programs which have proven of tremendous value are Astronomy and Nuclear Physics.

The most perceptive reason for the space program I have seen was in an editorial by Mr. Roscoe Drummond in **The Washington Post**, May 6, 1963. I would like to quote from that editorial:

"Through their mastery of roadmanship the Romans shaped their world for a long time.

"Through their mastery of seamanship the British did most to influence the affairs of the world for a century.

"Through their mastery of airmanship Britain and the United States turned back the tide of Hitler and Tojo.

"Through the mastery of spacemanship — through being foremost in outer space, not just first to the moon — it is now within the reach of the United States to affect greatly the shape of the world for the rest of this century, and, I believe, for some centuries ahead."

DISCUSSION

CROSSFIELD: Could you give us the altitude that the abort system takes the ejection seat to for opening of the chute?

SEE: Seventy thousand feet is the maximum altitude — this is on Gemini, now. We have an abort mode using ejection seats up to as high as 70,000 ft. We are hoping to decrease that altitude so that you go to spacecraft mode abort a little earlier but, as I mentioned, we're limited there by the retro-rocket power.

CROSSFIELD: I had in mind the pad abort altitude.

SEE: Oh! I don't remember a figure on that offhand, Scott.

CROSSFIELD: Pretty tight sequence, I figure.

SEE: Yes.

BILLINGS: R. K. Billings, Navy. Concerning your ejection seats, Elliot, I have two questions. Who is the contractor building them, and also, the technique you use for seat separation?

SEE: I think the seats are being built by Weber — I'm not certain of that; and the separation, I know you're referring to straps or something like that. I don't actually know what the system is on that. I believe it's just pulled away from you by the drogue chute, but I'm not positive if there is an additional separational method in there.

CROSSFIELD: The axes of the seat installation in the Gemini are canted. They go out at a diverging angle in the way they're installed.

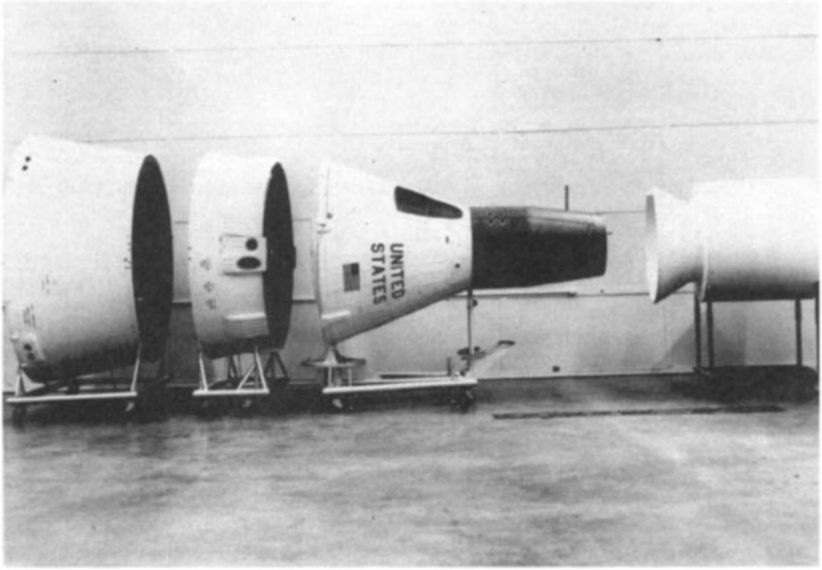

FIGURE 1

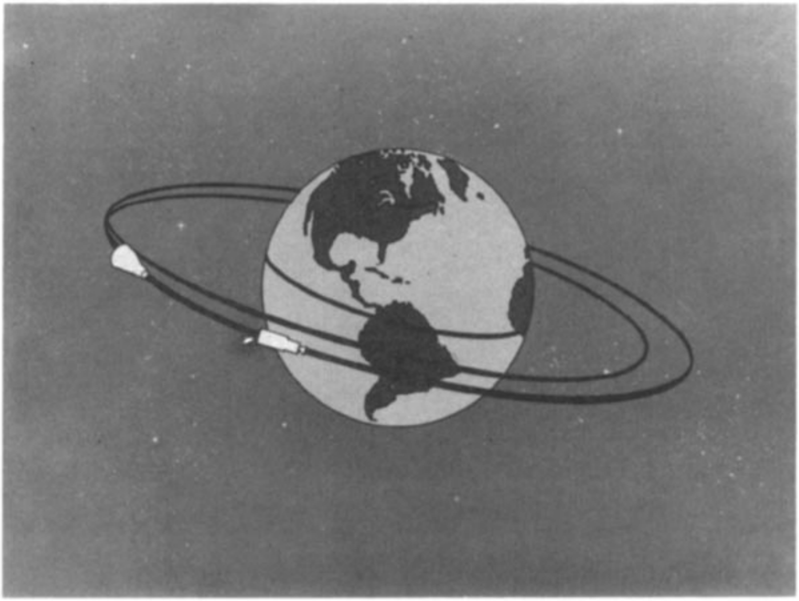

FIGURE 2

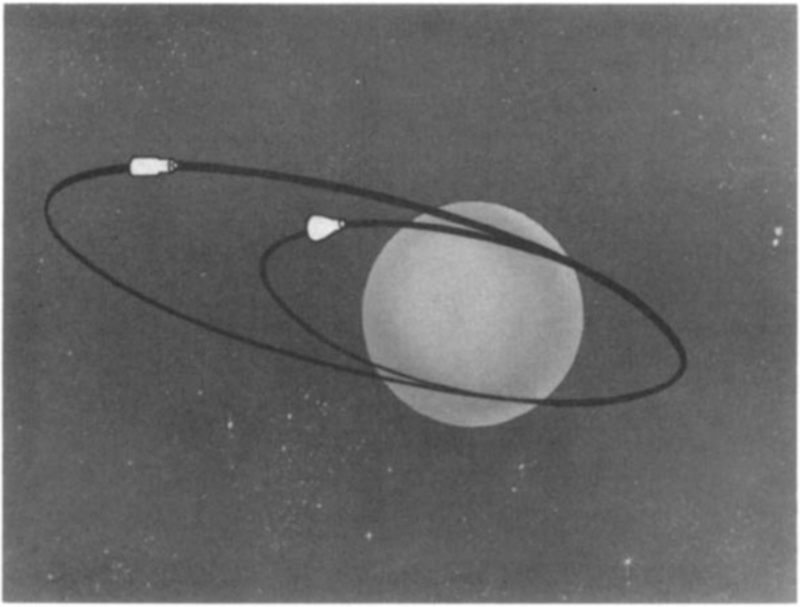

FIGURE 3

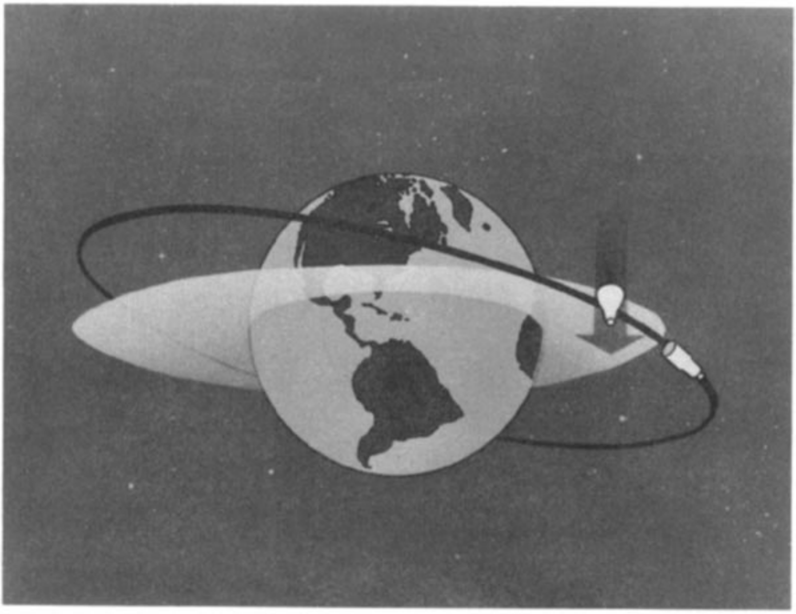

FIGURE 4

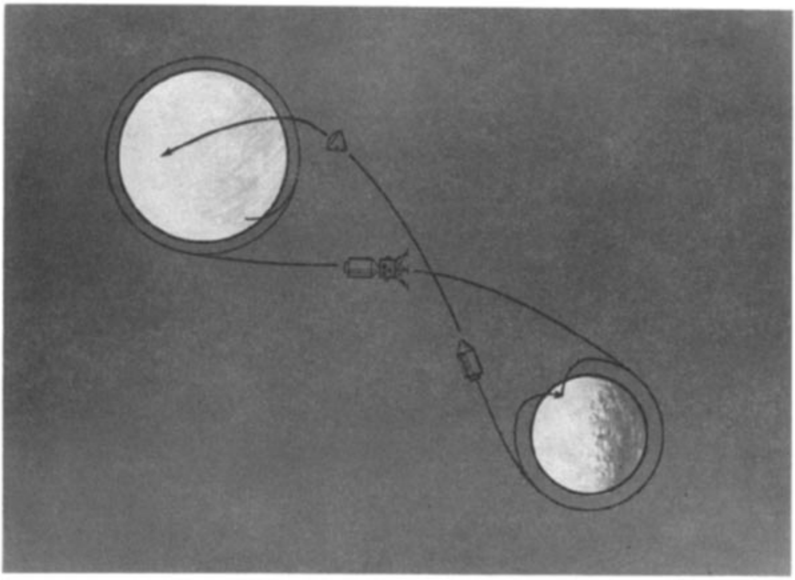

FIGURE 5

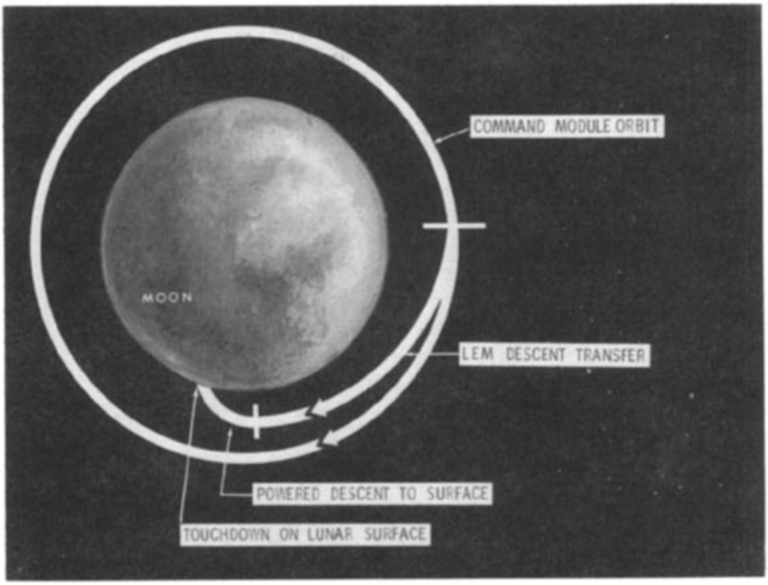

FIGURE 6

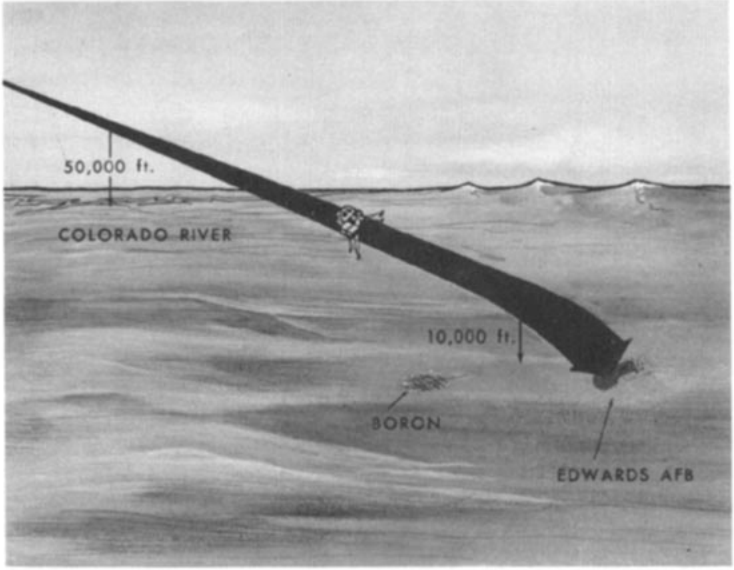

FIGURE 7

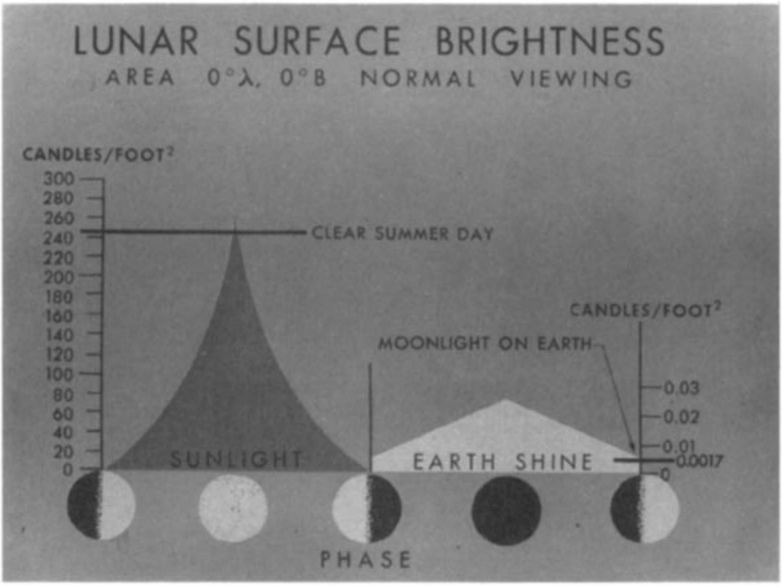

FIGURE 8

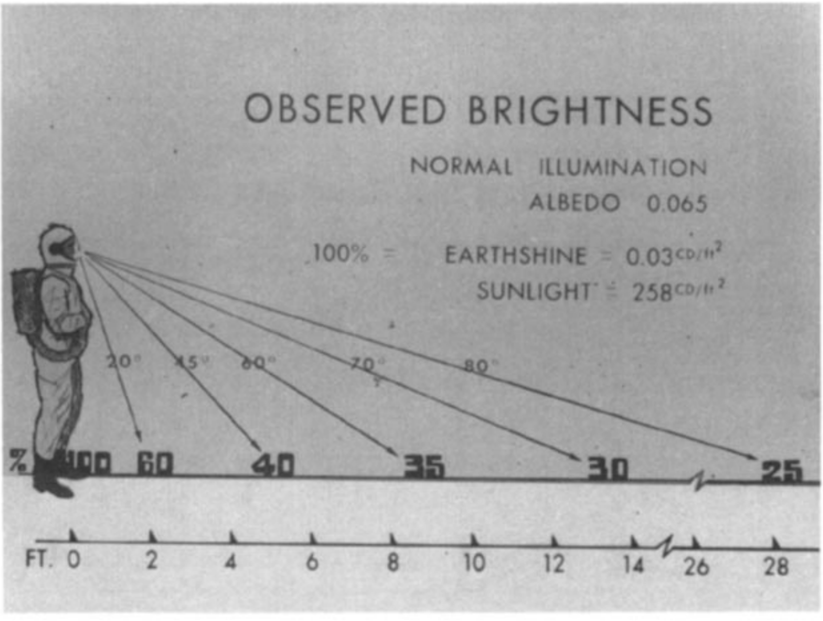

FIGURE 9