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VISUAL DISPLAYS FOR LUNAR MISSION SIMULATION

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VISUAL DISPLAYS FOR LUNAR MISSION SIMULATION

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INTRODUCTION

As presently planned, Project Apollo will have automatic capability for most phases of the lunar mission. The design overall probability of success of the Apollo mission is currently specified as 0.90.

In order to meet this number, the various subsystems must have very high reliability figures. To improve this number would appear to require some form of man-machine integration. Consequently, there is considerable interest in the NASA in the utilization of the astronaut to increase systems reliability.

The ability of the astronauts to perform many tasks was demonstrated in planned maneuvers in Project Mercury and probably more important was clearly demonstrated in the case of failures of automatic systems. This experience and a wealth of previous experience with man-machine combinations has shown that the reliability of systems can be increased through the proper integration of man and machine. A basic requirement in such a combination is that procedures be available for the man to follow. Preferably, guidance for the application of these procedures should be independent of complex automatic equipment. Many task areas of Project Apollo exist for which simple manual procedures have not been developed - for example, midcourse navigation, orbit establishment, lunar landing, etc. In such situations the first step is to

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develop piloting procedures for the various tasks and the next step is to demonstrate the pilot's proficiency in performing the tasks.

Inherent in the development of piloting procedures is the use of man's visual sense. At present not much visual experience exists in the space environment. In addition, it is not easy to acquire. At our present stage of development several years of preparation are invested in each manned space program. Each mission is planned in detail and practiced in order to acquire proficiency and assure success. This procedure dictates the use of simulators and inherently specifies that sophistication will be required if realism is to be obtained.

The present paper reviews the work at the Langley Research Center in this area, stressing simple piloting procedures which are based on visual cues, describes in some detail the use of visual cues, and how these cues will be generated in our simulators.

DEVELOPMENT OF PROCEDURE

The areas being examined at the Research Center are listed on figure 1. These include earth entry, rendezvous, docking, midcourse navigation, orbit ephemeris determination, lunar orbit establishment, powered lunar descent, hover and translation, and lunar launch. First let us see how we go about developing a simple piloting procedure. Consider, for example, a powered mission phase; in this situation the primary task of an automatic or manual guidance system is simply to point the thrust vector in the proper direction. Therefore, in looking for a simple manual guidance technique we are seeking visible references which an astronaut can use for orienting the thrust vector. Solutions to this problem take the steps shown on figure 2. First compute a fuel-optimum maneuver for the task. The next step is to examine the results to see how the thrust vector orientation changes relative to references external to the spacecraft. In most cases some reference exists such that the angle between the thrust vector and the line of sight to that reference remains about constant during the maneuver. The next step is to compute the maneuver based on use of the reference, and compare the results with the optimum maneuver. If the maneuver looks reasonable, an error analysis is made to determine the sensitivity of the procedure to reasonable operational errors. The most promising techniques at this stage are tried on a simulator.

LUNAR DESCENT

As an example of the technique, consider figure 3, which is concerned with lunar landing. It was assumed that after applying thrust, a lunar excursion module separated from a spacecraft which was in an 80-nautical-mile-altitude orbit around the moon. The module descended on a Hohmann transfer ellipse to a pericynthion altitude of 50,000 feet. At this point it then made a gravity-turn powered descent toward the lunar surface. On examining the orientation of the thrust vector relative to various references, it was noted that the angle between the excursion module thrust vector and the line of sight to the orbiting spacecraft remained very nearly constant during the powered descent phase (see fig. 4). Subsequent error analyses indicated that the orbiting spacecraft would be a suitable reference for manual control during the descent (refs. 1 and 2). Some enhancement of the orbiting spacecraft possibly by the use of a high-intensity flashing beacon or a filtering technique (see ref. 3) would be required to assure visual acquisition for the range of the maneuver. It is worth noting that the large variation in the angle K shown at the lower end of the altitude scale would, of course, require the astronaut to obtain some other visual reference. It so happens that at this point the excursion module is now operating within the altitude-speed range of many high-performance airplanes and our airplane experience would indicate that out-of-the-window view of the surface should suffice from this point to touchdown.

Studies along these lines have been made and others are in progress for many tasks associated with lunar landing missions. Manual procedures are being developed for most of these tasks. The procedures depend on the use of visual references for guidance. Some of these procedures already have been tried on available simulators, and some must await the activation of more sophisticated simulation devices.

ORBIT ESTABLISHMENT

Let us now review some additional lunar mission tasks, the procedures developed for each task, the visual cues required, and the generation of the cues in simulation devices. Consider the task of establishing an orbit around the moon. The problem is illustrated in figure 5. The vehicle approaches the moon on a hyperbolic trajectory. The task is to establish an 80-nautical-mile-altitude circular orbit, which means reducing the vehicle radial and tangential velocity components and altitude to the desired orbital values.

An analytical study showed that the lunar horizon would be a convenient reference for thrust vector orientation in the pitch plane, and, of course, stars would be good yaw or azimuth references. In fact, Mercury experience indicated that the astronaut could aline the capsule in yaw within a couple of degrees just by observing the convergence of the surface features through the window. In other words, it appears that the astronaut could navigate by aiming his vehicle using a scribed windshield or some other simple sighting device, possibly as shown in figure 6. Here we have shown the lunar surface and several stars. Elevation or pitch angles could be set using the lunar horizon. Convergence of the landscape on the grid could be used for azimuth alinement while the stars and the grid could be used to obtain a desired angular displacement. In order to provide these cues in a simulator, it is necessary to show the horizon, surface features, and stars, with proper relative motion to correspond to spacecraft movement. At present we do not have a device for projecting or displaying properly all of this information, so we have reverted to the use of a cathode-ray tube to generate representative stars and a horizon. The scribed lines on the CRT correspond to the spacecraft window lines. This simulator will be used for a preliminary evaluation of the procedures for establishing orbits. By next summer the Lunar Orbit and Landing Approach simulator (LOLA) should be operational, and we will have a good means of generating the horizons and surface features. At that time we will be using star projectors for star displays. The LOLA simulator will be described in detail subsequently.

ORBIT EPHEMERIS DETERMINATION

The next task to be examined is that of orbit ephemeris determination. The problem is simply that of finding the characteristics of an orbit as determined from onboard sightings. Two basic procedures for doing this have been proposed as shown in figure 7. One depends on the use of lunar landmarks and measurements of such parameters as rotation of a line-of-sight, altitude, altitude rate, etc. The other depends on taking sightings on orbiting spacecraft and determining range and range rate. Thus, there are two different techniques to evaluate, and the visual cues to be generated are completely different. The one requiring lunar surface features will be evaluated on LOLA. The other requires the generation of a spacecraft image. In this case the spacecraft will probably be represented by a light spot.

LUNAR LANDING

The most critical phase of the lunar mission will be the final part of the powered descent and touchdown. Experience with airplanes and helicopters has demonstrated that man can perform landings much better and more reliably than any automatic system. The lunar landing therefore is one task area which will be investigated with as much realism as practical. Here, of course, the visual cues required are the lunar surface features, and since appreciable accelerations are involved, motion cues become important. The final portion of the lunar landing will be studied on the Lunar Landing Research Facility which will be described subsequently.

LUNAR ORBIT AND LANDING APPROACH SIMULATOR

Currently under construction at the Langley Research Center are two rather sophisticated simulators. One of these is the Lunar Orbit and Landing Approach simulator (otherwise known as LOLA), and is illustrated in figure 8. This simulator consists of four models of the lunar surface, viewing systems to transmit views of the models to the display area, and a four-porthole display system. The four models were selected on the basis of a desired simulated altitude range of about 200 miles to 200 feet for a wide range of trajectories. Design considerations included a minimum distance of viewing optics to the models of 3/4 of an inch, and a practical size for construction and housing in an existing structure. The region around Crater Alphonsus was selected as the landing site for simulation studies because of scientific interest and because regions of the most rugged mountains on the moon lie on the approach. Therefore, it presents the pilot with an exacting navigational task. Orbital inclinations up to 15° can be simulated with the spherical model. The surface of the spherical model will be smooth with the lunarscape painted on plastic gores which are then mounted on the surface. All other models are in relief with painted shadow patterns to give the proper appearance. All models are internally or backlighted. Direct solar illumination was chosen as the lighting condition so that the lunar surface features would appear under low contrast. This should reduce the facility to see the features and provide an adverse viewing condition as compared with other lighting conditions in which shadows are more prominent.

The models are viewed by clusters of TV cameras mounted on transport mechanisms. The transport mechanisms have three translational degrees of freedom. In addition, the camera clusters are gimballed to provide three angular degrees of freedom so that a full six-degree-of-freedom motion can be simulated. One group of four TV cameras furnishes the display information to the pilot at any given instant. A simulated vehicle will have four portholes, a TV camera providing each with a 65° simulated field of view. The display will present the pilot with realistic terrain features such as the irregular lunar horizon and closeup features when in the final landing approach.

Pilot control signals are transmitted to the computer which, in turn, drives the transport and gimbal mechanisms so that the pilot in effect flies the cameras over the lunar surface. During a descent, the system viewing the spherical model of the moon will furnish display information to the pilot until the lower limit of travel is reached. Before this lower limit is reached the second camera cluster is automatically switched on for map 1. Similar switching will be made through the remainder of the descent.

The size, scale factors, and altitude range of each model are as follows:

Model	Size	Altitude range	Model scale
Sphere	20-foot D	200 miles to 7 miles	1 inch = 9 miles
1	15 feet × 40 feet	7 miles to 1.5 miles	1 inch = 2 miles
2	33 feet × 25 feet	1.5 miles to 3/8 mile	1 inch = 1/2 mile
3	Ellipse 34.9-foot major axis 22-foot minor axis	3/8 mile to 200 feet	1 inch = 200 feet

In order to use the sphere and map 1 before the TV system is operational, a 180° motion-picture camera-projector has been developed. Preprogramed trajectories will be filmed. The motion pictures will then be projected within the sphere giving a 180° field of view. The pilot will be an observer and will not have control over the display. This presentation will be used to test man's ability to perform observational tasks which would precede any control action and to determine his orbital ephemeris.

LOLA should help define those control tasks best performed by man or machine and thus will determine an effective man-machine integration for the lunar mission. Studies with the preprogramed trajectories should begin in the latter part of this year, and the complete system should be in operation about a year later.

LUNAR LANDING RESEARCH FACILITY

Because gravity on the moon is 1/6 that of the earth, thrust levels for lunar operations are very low compared with those required for VTOL flight on earth. To produce reasonable horizontal accelerations for braking and maneuvering during lunar landing, large attitude angles, up to 30° or more, will be required. This may pose serious visibility, attitude, and thrust-control problems. A facility designed to study the piloting problems close to the lunar surface is presently under construction at Langley. This simulator and its associated equipment is known as the Lunar Landing Research Facility. Simulation with this facility begins at about the altitude where LOLA stops.

An overall layout of the facility is shown in figure 9. The gantry supports a traveling crane from which the vehicle is suspended. The crane system supports 5/6 of the weight of the vehicle through servocontrolled vertical cables, while the remaining 1/6 of the weight pulls downward and simulates the lunar gravitational force. The overhead crane is slaved to move with the vehicle linear motions to keep the cables vertical. A gimbal system on the vehicle permits angular freedom in pitch, roll, and yaw.

Vehicles weighing up to 20,000 pounds, and as large as the full-scale lunar excursion module used in the Apollo Project, can be tested on this facility. The pilot can maneuver in complete six degrees of freedom in a volume 400 feet long, 165 feet high, and 50 feet wide. Through the use of a catapult, initial velocities up to 50 fps horizontally and 40 fps vertically can be provided.

A photograph of the general research test vehicle is shown in figure 10. The vehicle gross weight is 10,000 pounds including a two-man crew and 3,300 pounds of fuel. Fuel is 90-percent hydrogen peroxide. The main motors provide 6,600 pounds of thrust with a 10-to-1 throttling range. Attitude motor thrust is ground adjustable to produce angular accelerations from 0.1 to 0.5 rad/sec^2 about all axes. The fuel load will permit about 3 minutes of operation.

The pilot's bubble can be masked to determine the effect of the viewing area on his ability to land safely. It is anticipated that requirements for instrument displays will be developed as the simulation program proceeds. The establishment of requirements for performing a lunar landing will be accomplished by measuring pilot performance. Piloting techniques, visibility, and abort modes will be major items of study using this simulator. Construction of this facility was started in September 1962, and is now nearing completion. Research studies will start sometime this summer.

CONCLUDING REMARKS

In conclusion, the Langley Research Center has been examining, through analytical and simulation studies, simple guidance techniques for pilot control of various tasks associated with the lunar mission. These simplified techniques and pilot utilization should increase the reliability of Project Apollo and other manned space missions. Results of simulator studies conducted thus far have shown that, given proper information, pilots can perform rendezvous and docking although these missions have not actually been performed in space. The usefulness of simulator devices, however, has been demonstrated in Project Mercury. Simulation devices such as LOLA and the Lunar Landing Research Facility will provide information necessary for the Lunar and other space programs.

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EARTH ENTRY
RENDEZVOUS
DOCKING

MIDCOURSE NAVIGATION
ORBIT EPHEMERIS DETERMINATION

LUNAR ORBIT ESTABLISHMENT
POWERED LUNAR DESCENT
HOVER AND TRANSLATION
LUNAR LAUNCH

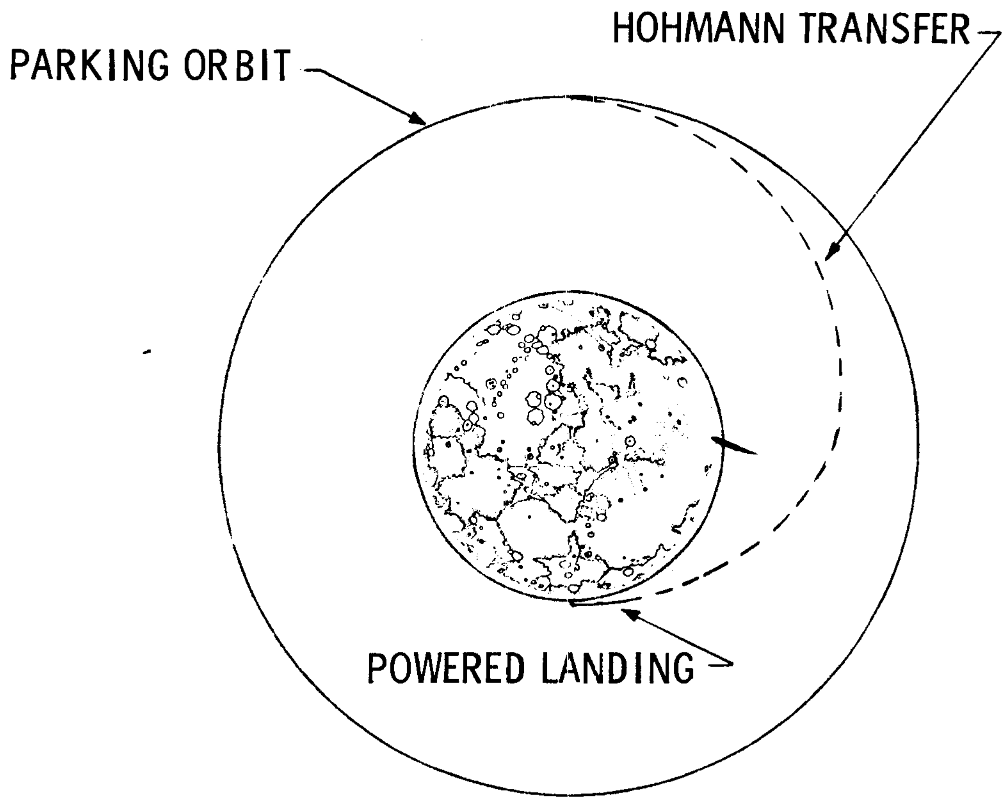
NASA

Figure 1.- Task areas under study.

1. COMPUTE OPTIMUM MANEUVER
2. EXAMINE THRUST VECTOR ORIENTATION
3. RECOMPUTE MANEUVER USING VISUAL REFERENCE
4. ERROR ANALYSIS OF TECHNIQUE
5. MAKE SIMULATOR STUDY USING TECHNIQUE

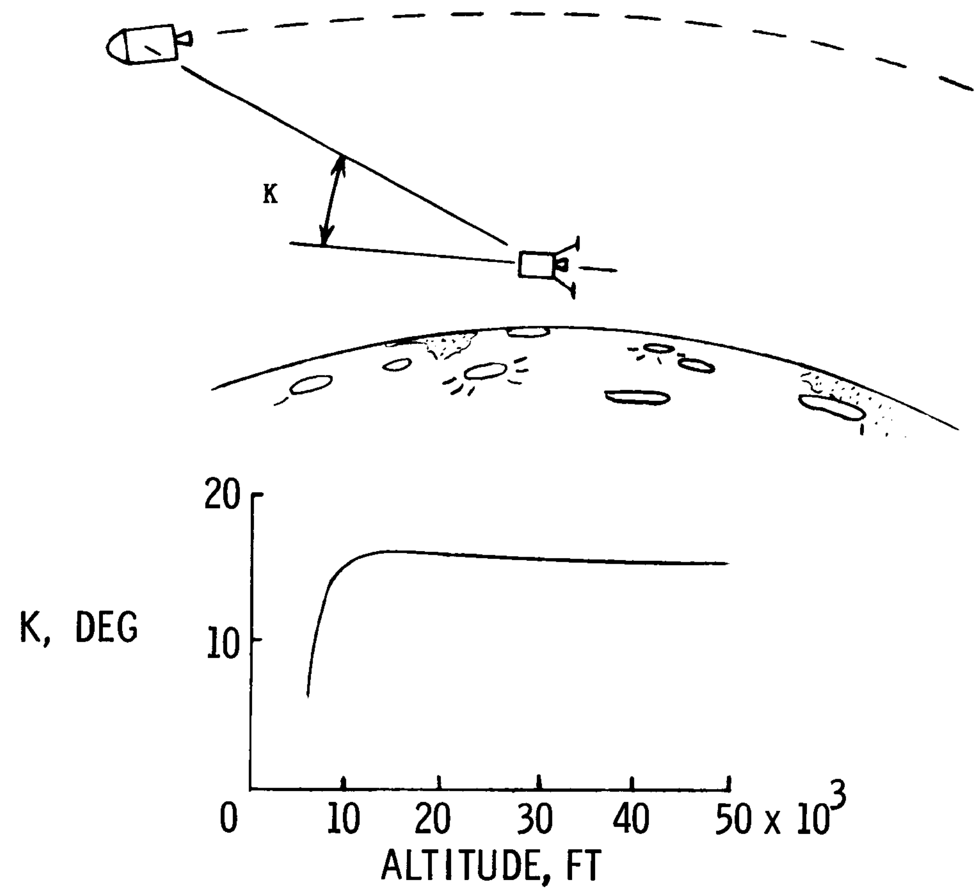
NASA

Figure 2.- Procedure for selection of simplified piloting technique.



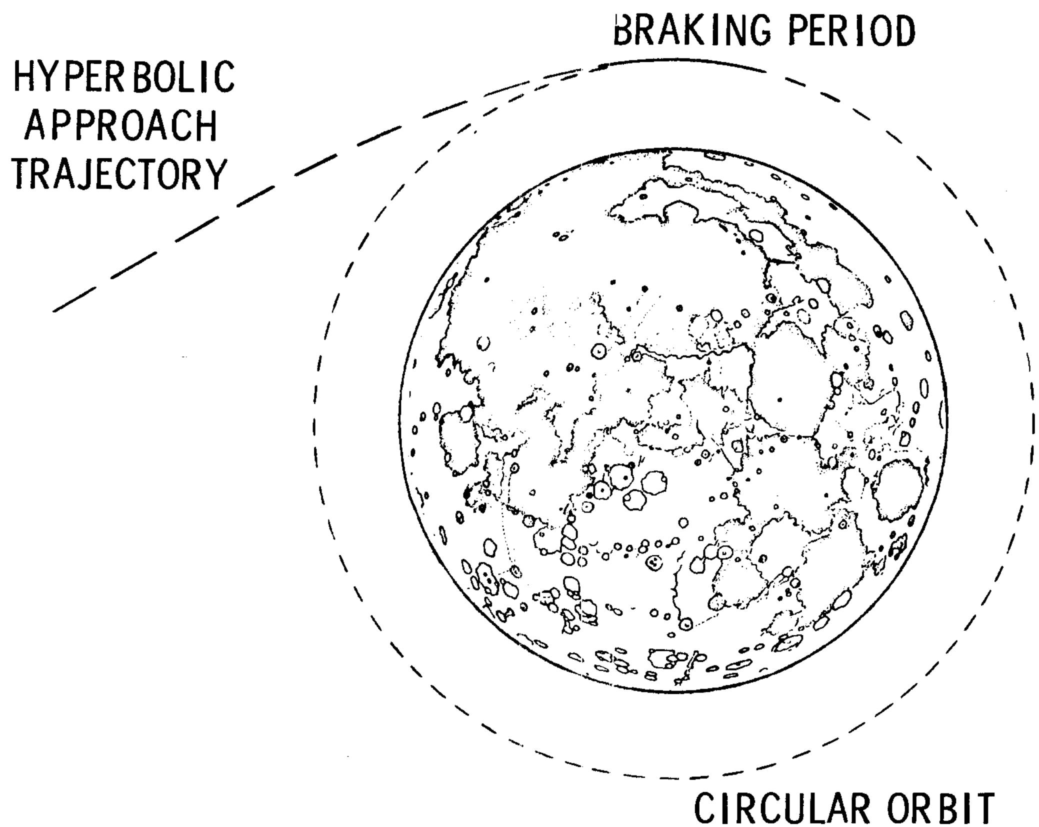
NASA

Figure 3.- Lunar descent.



NASA

Figure 4.- Lunar landing.



NASA

Figure 5.- Orbit establishment.

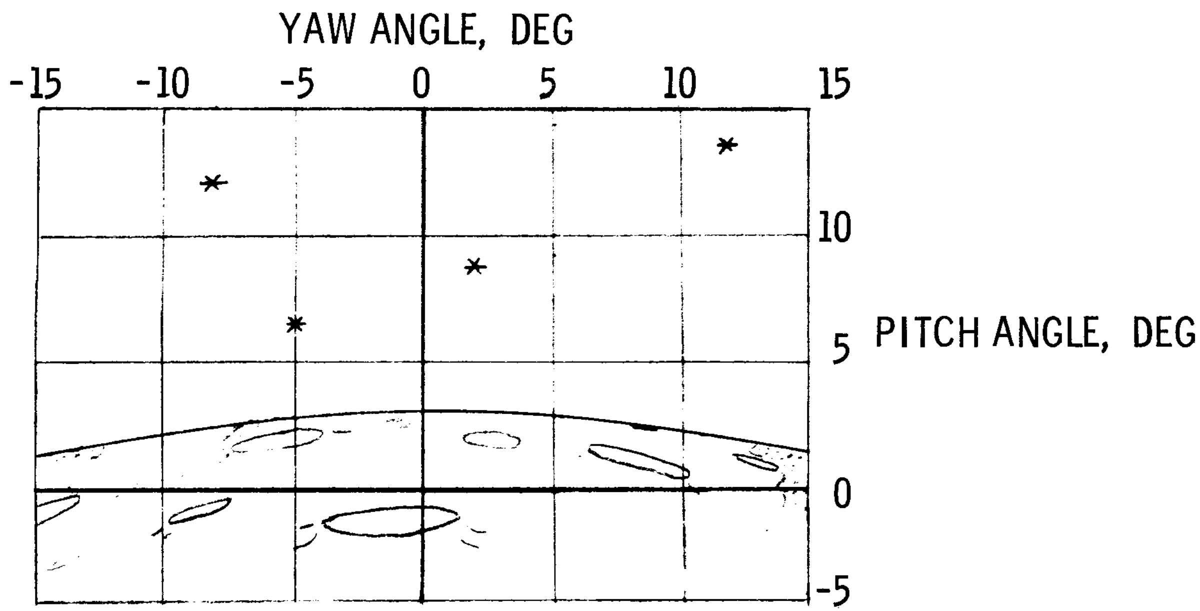


Figure 6.- Window for vehicle alinement.

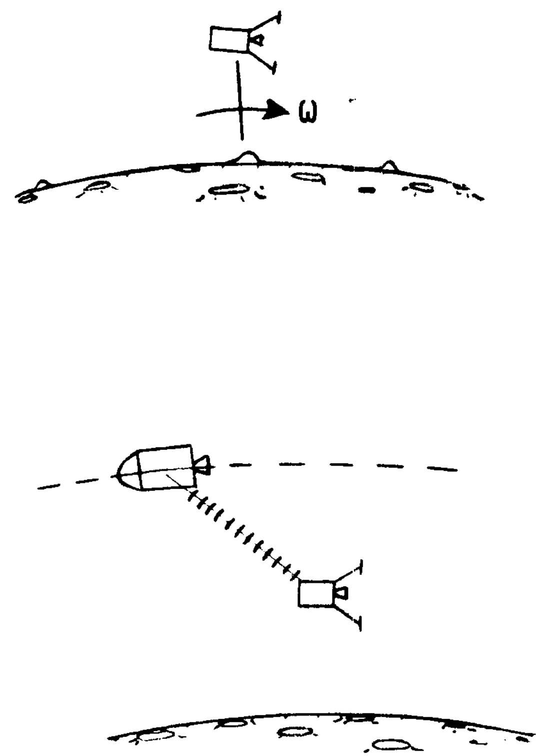


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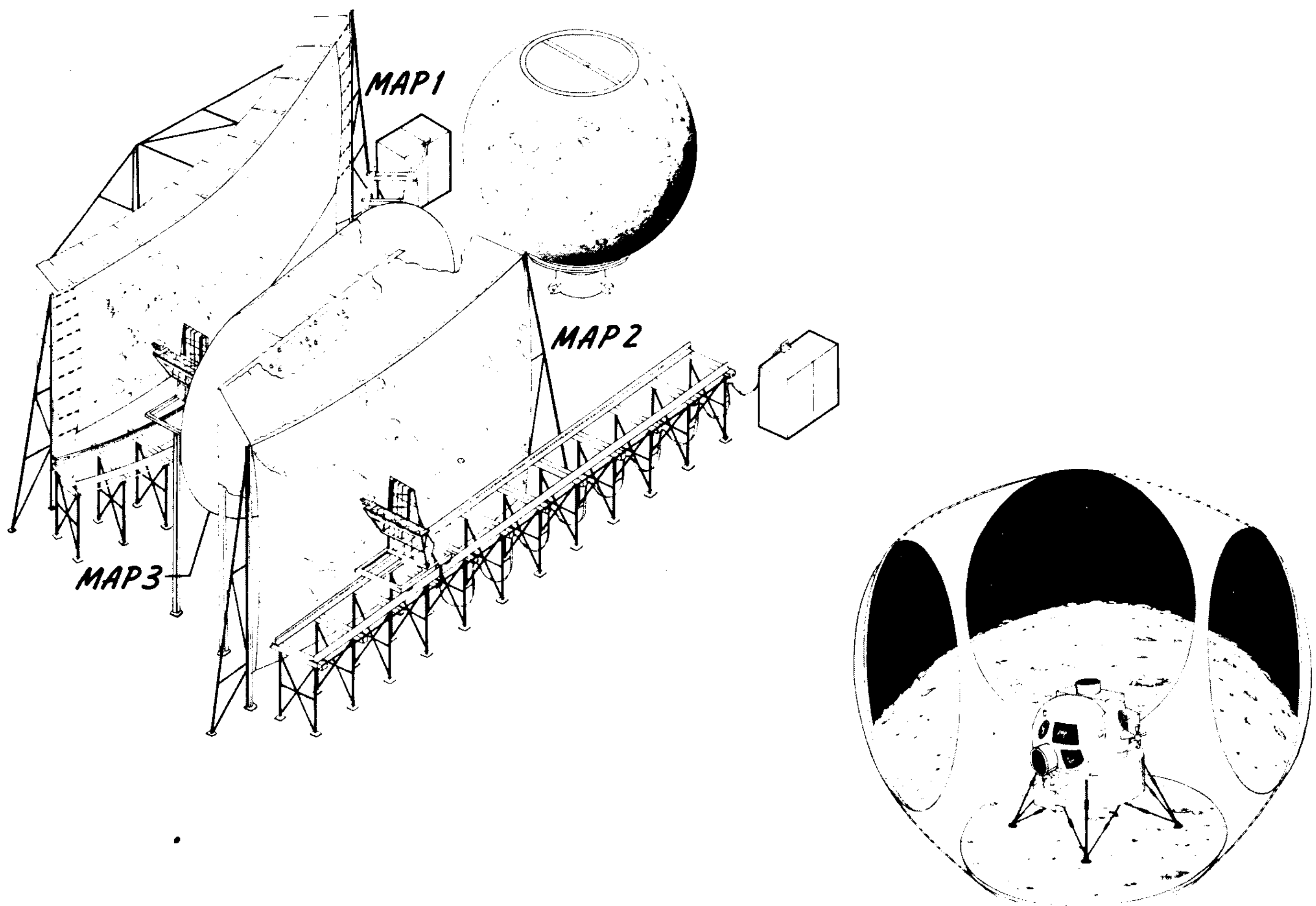
Figure 7.- Orbit ephemeris determination.



NASA

Figure 8.- Lunar Let-Down Simulator.

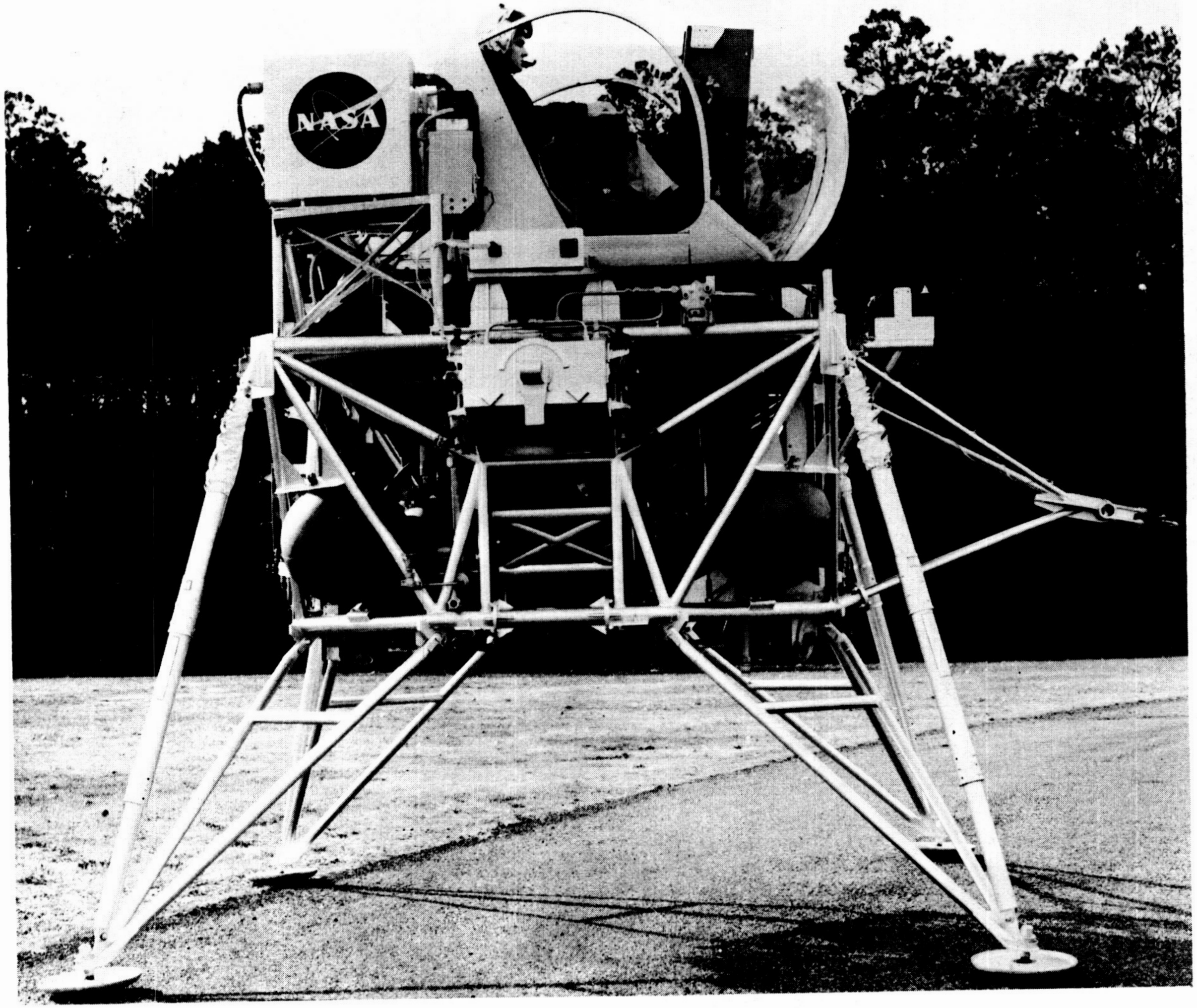


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Figure 10.- General research vehicle for Lunar Landing Research Facility.

NASA-Langley, 1964

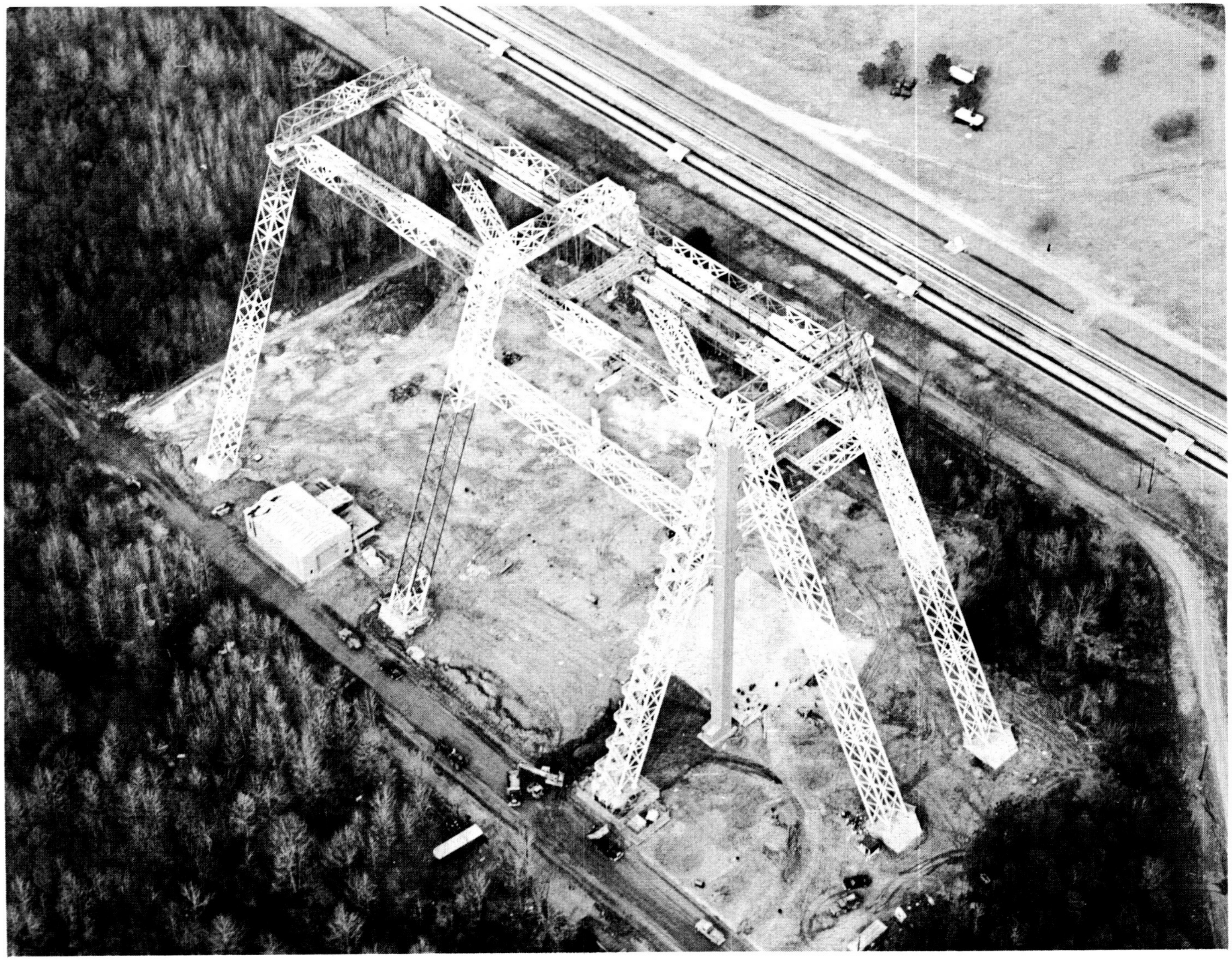

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Figure 9.- Lunar Landing Research Facility.