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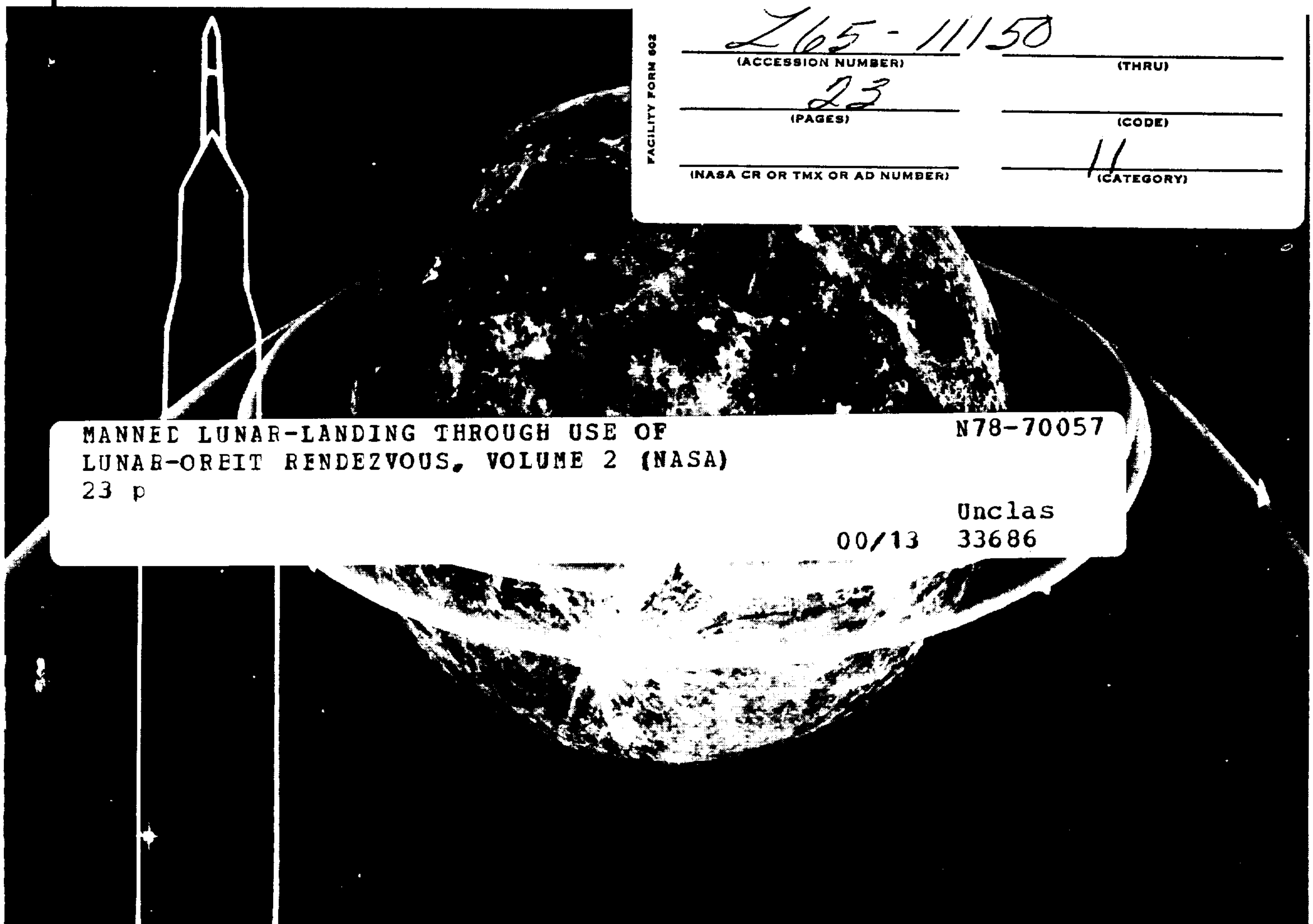

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MANNED LUNAR-LANDING through use of LUNAR-ORBIT RENDEZVOUS

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PART III

A P P E N D I X

ADDITIONAL FACILITIES AND STUDIES (UNDERWAY AND PLANNED) IN SUPPORT OF A MANNED LUNAR LANDING

This appendix contains short descriptions of a number of facilities and studies not described elsewhere (both underway and planned) which will contribute to the achievement of a manned lunar landing. It will be noted that emphasis has been given in this work to proof of the thesis that man with visual and in some cases supplementary electronic sensing is capable of handling the various operations pertinent to a manned lunar mission.

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Establishment of a Lunar Orbit

Simulation study of pilot's control from hypersonic velocity to a desired lunar orbit.- Although this phase is not peculiar to the lunar-rendezvous technique for landing a man on the moon, it is included since it influences the landing, abort, and take-off phases. For a realistic study of this phase, we must establish the accuracies with which a human can establish the Ephemeris of a lunar orbit; this was part of the simulation study made.

After appropriate midcourse corrections, the space vehicle will be on a hyperbolic trajectory approaching the moon. Basically the problem of establishing a close circular orbit consists of application of retro-thrust in such a manner as to make the point of closest approach occur at a selected altitude above the lunar surface, and simultaneously modifying the velocity to the magnitude and direction required for a circular orbit. Presuming that the vehicle is in the proper orbit plane, the parameters which determine the orbit characteristics are altitude, radial velocity, and circumferential velocity. The desired circular orbit conditions are zero radial velocity, some selected altitude, and a circumferential velocity equal to circular orbital velocity at that altitude. These three parameters therefore must be measured quite carefully and displayed to the pilot, so that he can apply any required correction through his control of thrust and vehicle orientation.

In order for a pilot to control the orbit characteristics in the simulator, he was presented a display indicating the vehicle orientation and attitude rates in addition to the three orbit parameters already mentioned. The pilot was then given the task to apply correct thrust to establish an orbit.

It was assumed that a manned space vehicle was approaching the lunar surface on a hyperbolic trajectory which would have a point of closest approach at an altitude of about 56 miles and a velocity at that point of 8,500 feet per second. The pilot's task was to establish a circular orbit at a 50-mile altitude. The pilot was given control of the thrust (along the vehicle longitudinal axis) and torques about all three body axes.

The information display given to the pilot was a hodograph of the vehicle rate of descent and circumferential velocity, an altimeter, and vehicle attitude and rate meters. The general procedure used in the investigation was to permit the pilots to become familiar with the instrumentation, controls, and vehicle dynamics by flying a simple "nominal" trajectory for which the operating mode was specified. The pilots had no difficulty flying this nominal trajectory, and used only about 2 percent more fuel than theoretically required to accomplish the task as shown in figure 1. The results of the investigation showed that the pilots soon became adept at flying the simulator, and could manage "off-nominal" trajectories with little or no difficulty. See figure 2. The indicated fuel consumption generally was about 1 to 3 percent of the initial vehicle mass more than that required by use of a two-impulse Hohmann maneuver. The results of this simulator study have been published in NASA TN D-917 by Queijo and Riley.

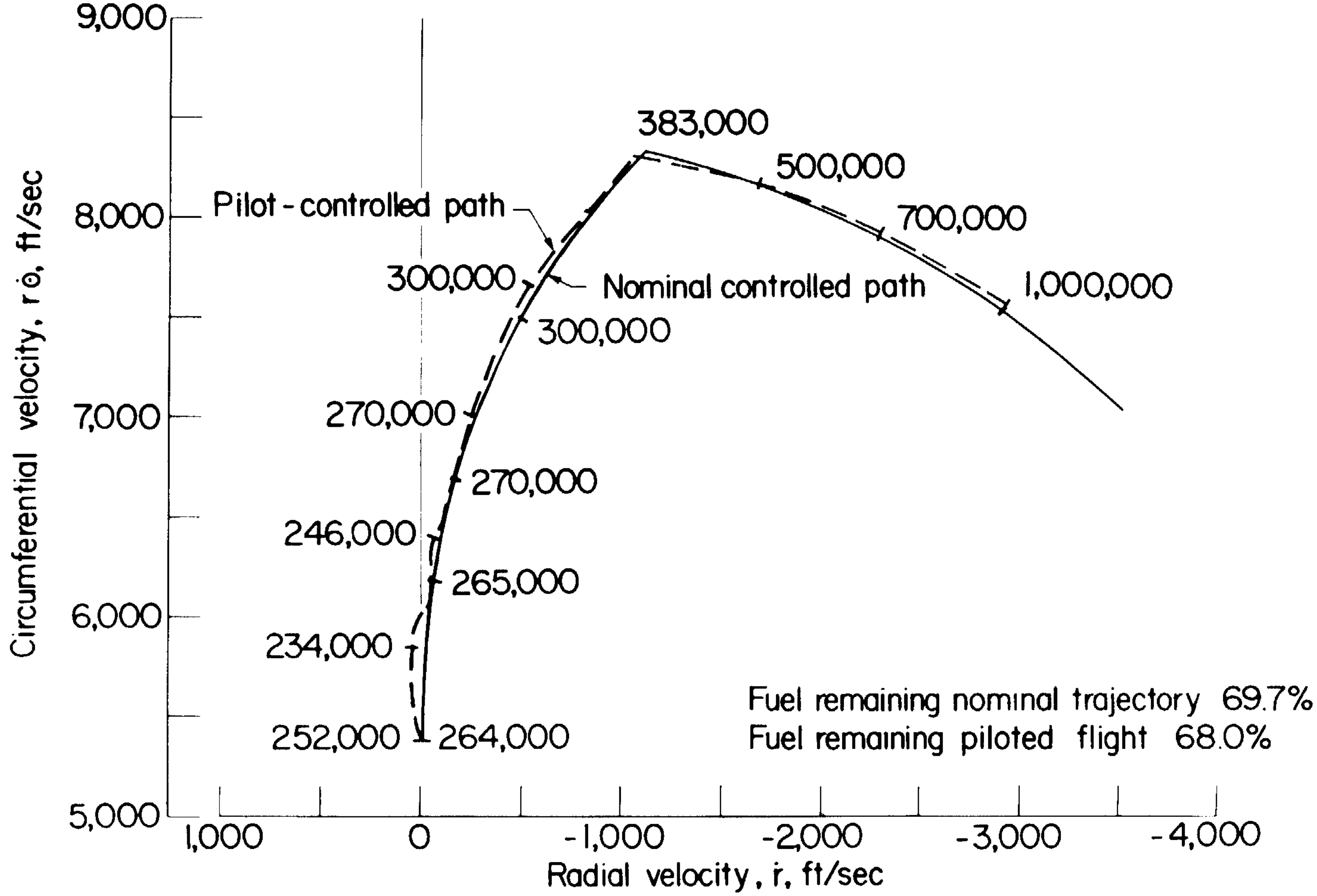


Figure 1.- Typical flight starting with nominal ballistic trajectory. L-1303

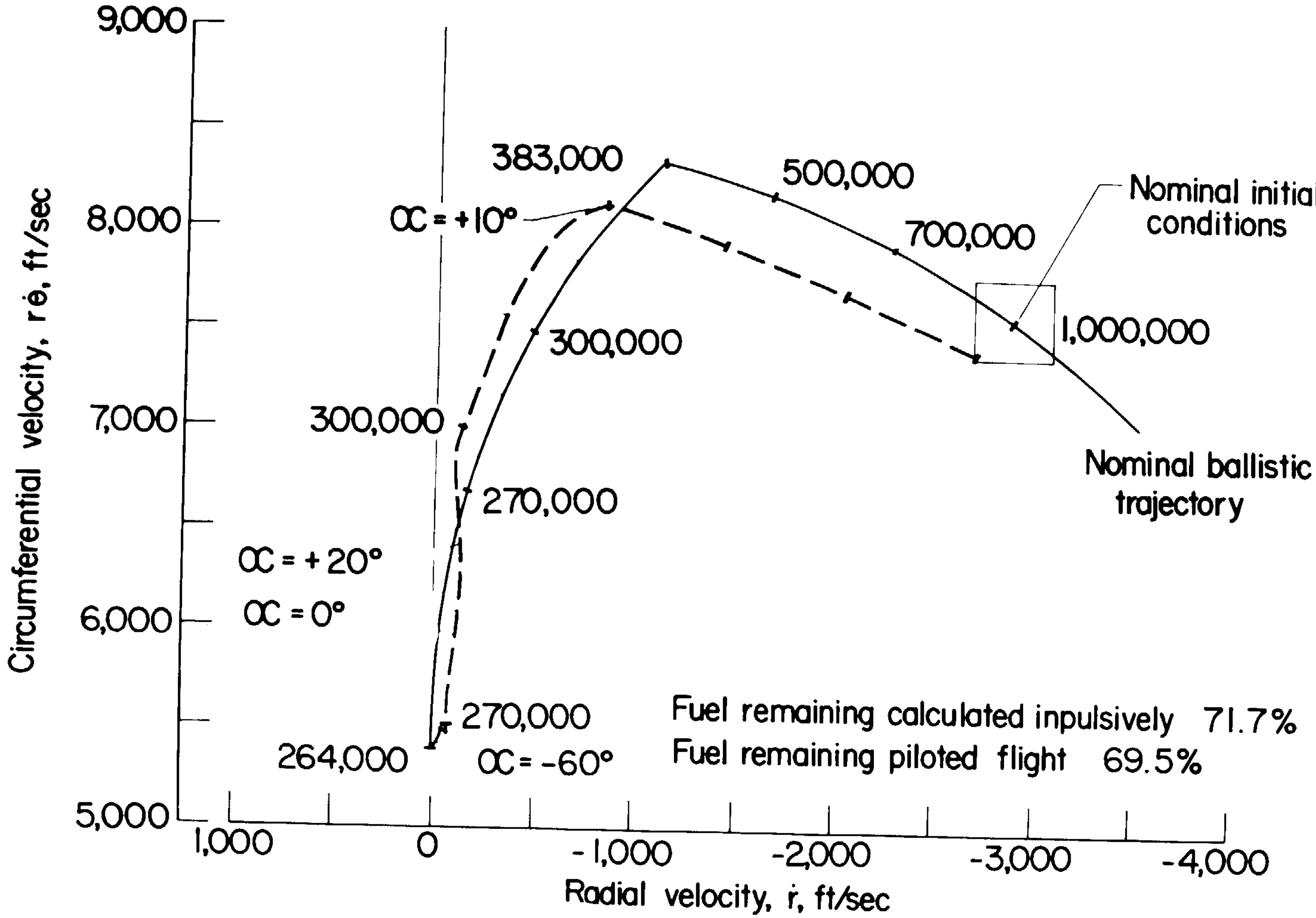


Figure 2.- Flight starting with $r\dot{\theta}$ and $\dot{r}$ each 200 ft/sec less than nominal. L-1302

Lunar Letdown Phase

Simulation study of visual control of a vertical descent.- A preliminary study, using a visual simulation, has been completed to establish a pilot's ability to judge and control the rate of descent during a vertical approach from a lunar orbit.

The vertical descent phase of a lunar letdown to the moon's surface was controlled by the pilot in alternate periods of free fall and rocket braking. The motion in descents, from 125,000 feet to 25,000 feet and from 25,000 feet to 2,000 feet, was simulated with visual cues provided by coupling an analog computer to servo-drive an optical projector. Rate of descent was seen as growth of the projected lunarscape features. The pilot was seated in a fixed-base cockpit viewing the lunarscape as through a hatch. A photograph, figure 3, shows the equipment in operation.

Results of the tests are shown in figure 4. The pilots controlled the rate of descent relatively near the human threshold of perception of descent rate, resulting in an excessive use of fuel.

Further studies are planned utilizing a paired set of zoomar projection lenses to obtain a wider range of simulated altitude. These tests will also include visual aids to allow the pilot to measure descent rates and to predict the near-optimum time to initiate rocket firing for efficient control of the letdown maneuver.

Helicopter tests to establish a human's ability to control position during a vertical descent.- Autorotation flights were made using a helicopter descending from 10,000 feet over marshland near Wallops Island as shown in figure 5. Radar position information was then utilized to determine the cone of position control the pilot generated during his descent. One set of flights has been made and one set is scheduled for this month. Upon completion of the vertical phase, similar tests are contemplated for a slant-approach to landing technique.

Instrumented control study of a lunar letdown.- A preliminary simulation study of a pilot controlling a slant-approach to a lunar landing area was made with an all-instrument display. This study was completed primarily to obtain the initial conditions of velocity, altitude, mass, and relative position of the parent orbiting vehicle for a study of the problems of aborting the landing at any time during the approach. A future study, section 2(d), will present visual cues to the pilot to determine the minimum instrumentation requirements for this task.

The simulation maneuvers to touchdown were controlled by a pilot seated in a fixed-base cockpit with an instrumented display of altitude, vertical velocity, vehicle attitude, and flight-path velocity. The pilot accomplished the maneuvers by controlling vehicle attitude and thrust.

In control, an initial thrust period was used to establish (from a lunar orbit) an approximate ballistic path to a landing sight about 45° around the moon's circumference. Final braking could be controlled down to about 2,000 feet of the moon's surface.

Results indicate that the pilot's choice is to use continuous thrust for the final braking maneuver and to establish a hover condition. The effects of engine thrust capability and specific impulse on fuel consumption is shown in figure 6. Fuel used during hover would consume about an additional 1.5 percent of the initial mass/min.

Simulation study of a piloted lunar letdown.- After establishing an initial lunar orbit, the pilot can modify the orbit characteristics by proper application of thrust. This might be desirable in order to pass the orbit over a specific point on the lunar surface or to establish a more precise circular orbit. The next phase is the departure of the lunar lander from the mother ship, with subsequent deorbit, letdown, and landing.

A six-degree-of-freedom, fixed-base analog simulator study is currently underway to determine the ability and efficiency of pilots to control the deorbit and letdown phase of the lunar landing, and the control and display requirements. Photographs of the control console used in the initial studies are shown in figure 7. The pilot is given control of thrust along the vehicle longitudinal axis, and moment control about all three body axes. The display as used in initial tests showed altitude, vertical velocity, circumferential velocity, vehicle angular rates, and vehicle attitude.

In the actual lunar landing vehicle the altitude, radial velocity, and tangential velocity components may be measured using onboard pulse doppler radar. Vehicle attitude and angular rates can be measured by use of an inertial table or, preferably, by visual observation of the lunar surface and horizon.

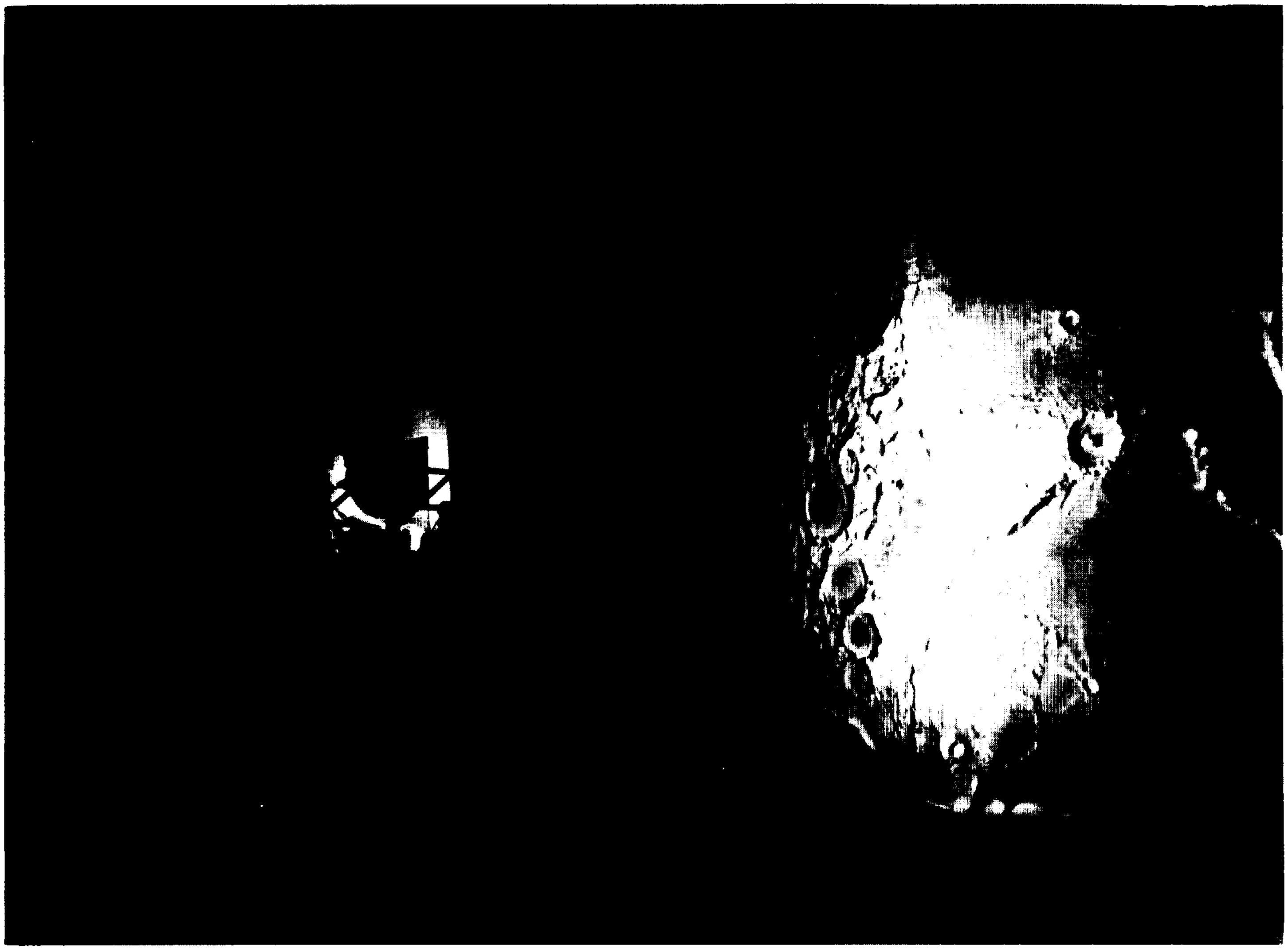


Figure 3.- Pilot-controlled vertical descent simulator. L-61-5040

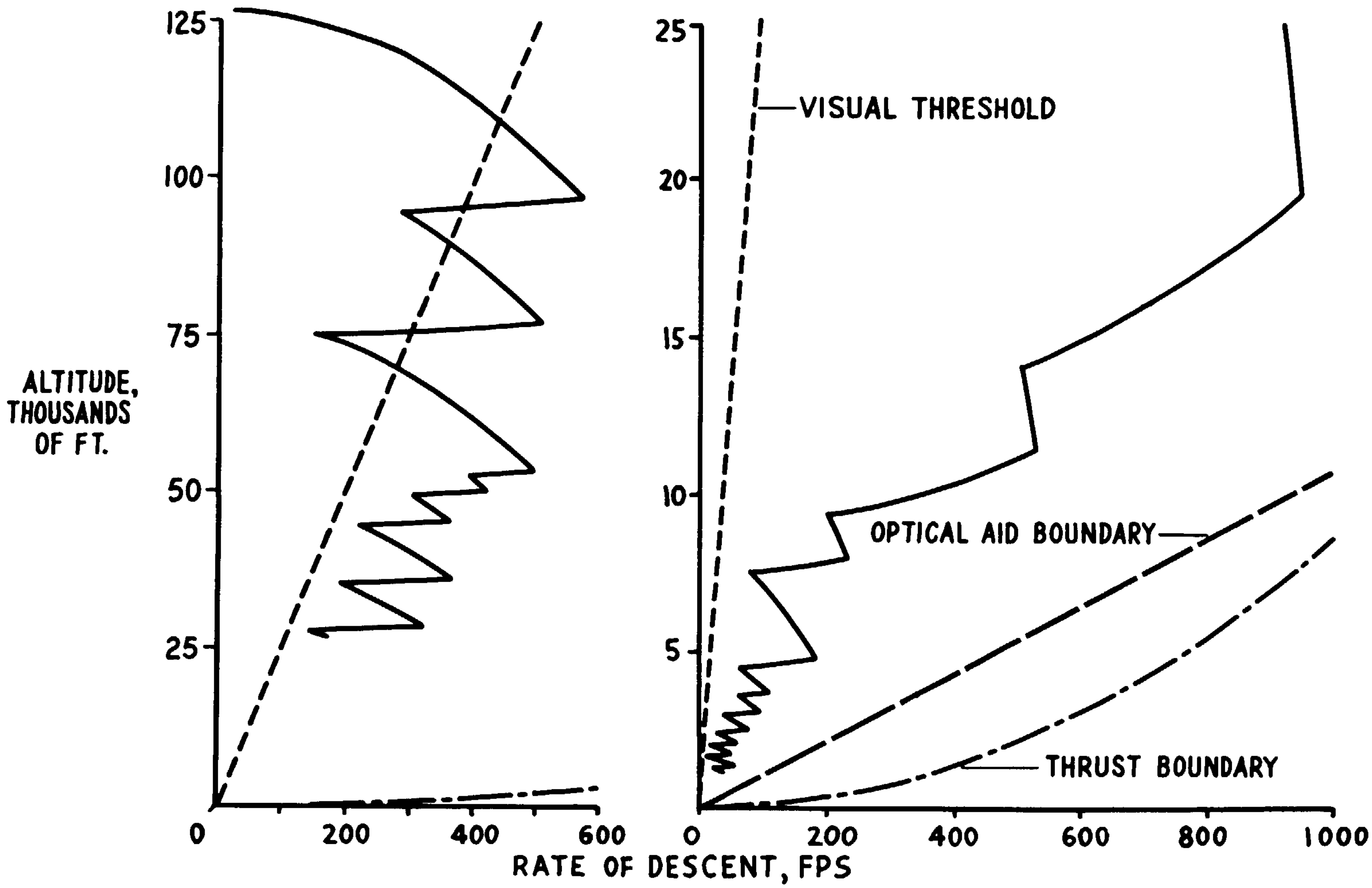


Figure 4.- Vertical descent simulator results.

L-1310

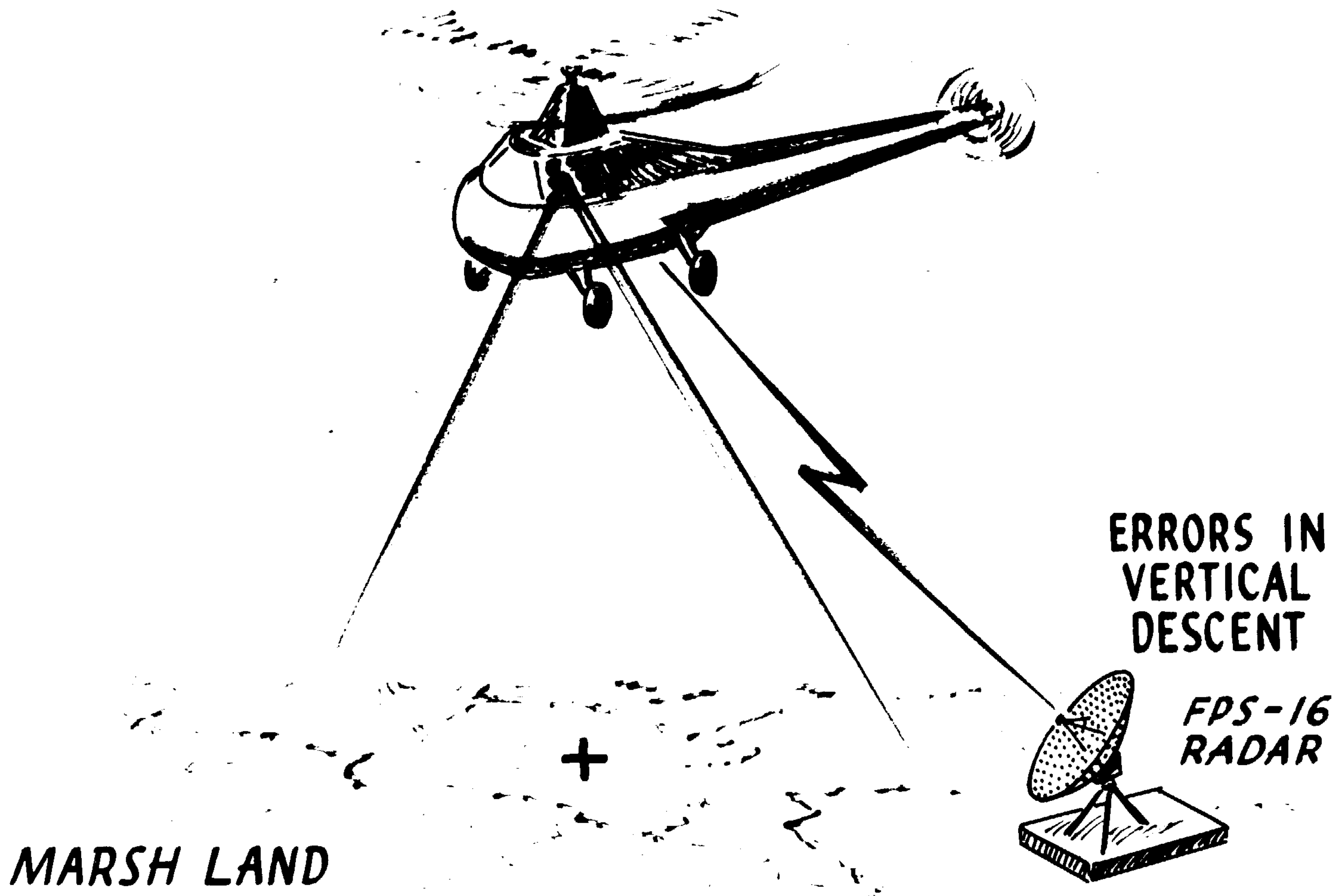


Figure 5.- Pilot-controlled vertical descent. L-1294

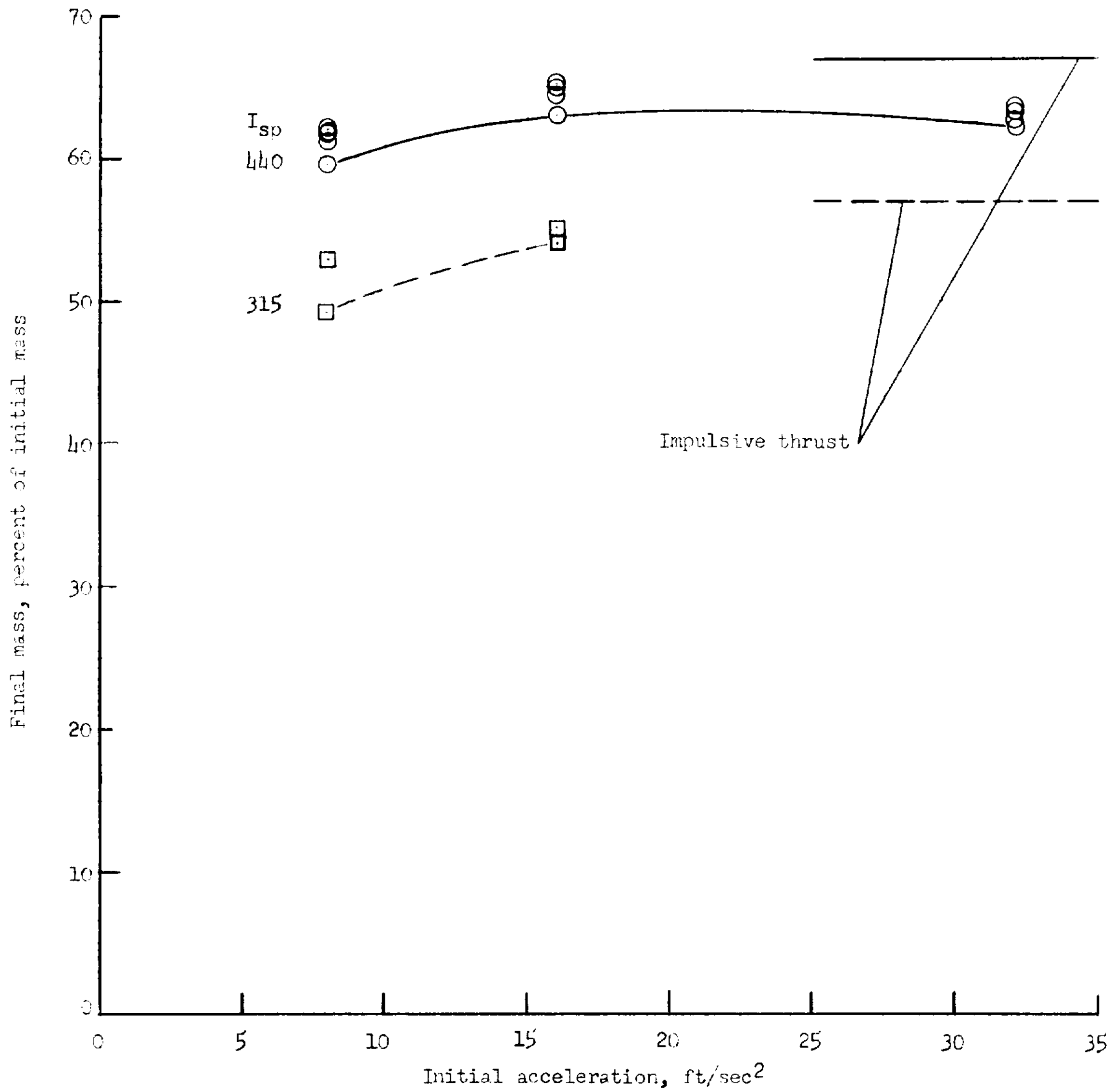
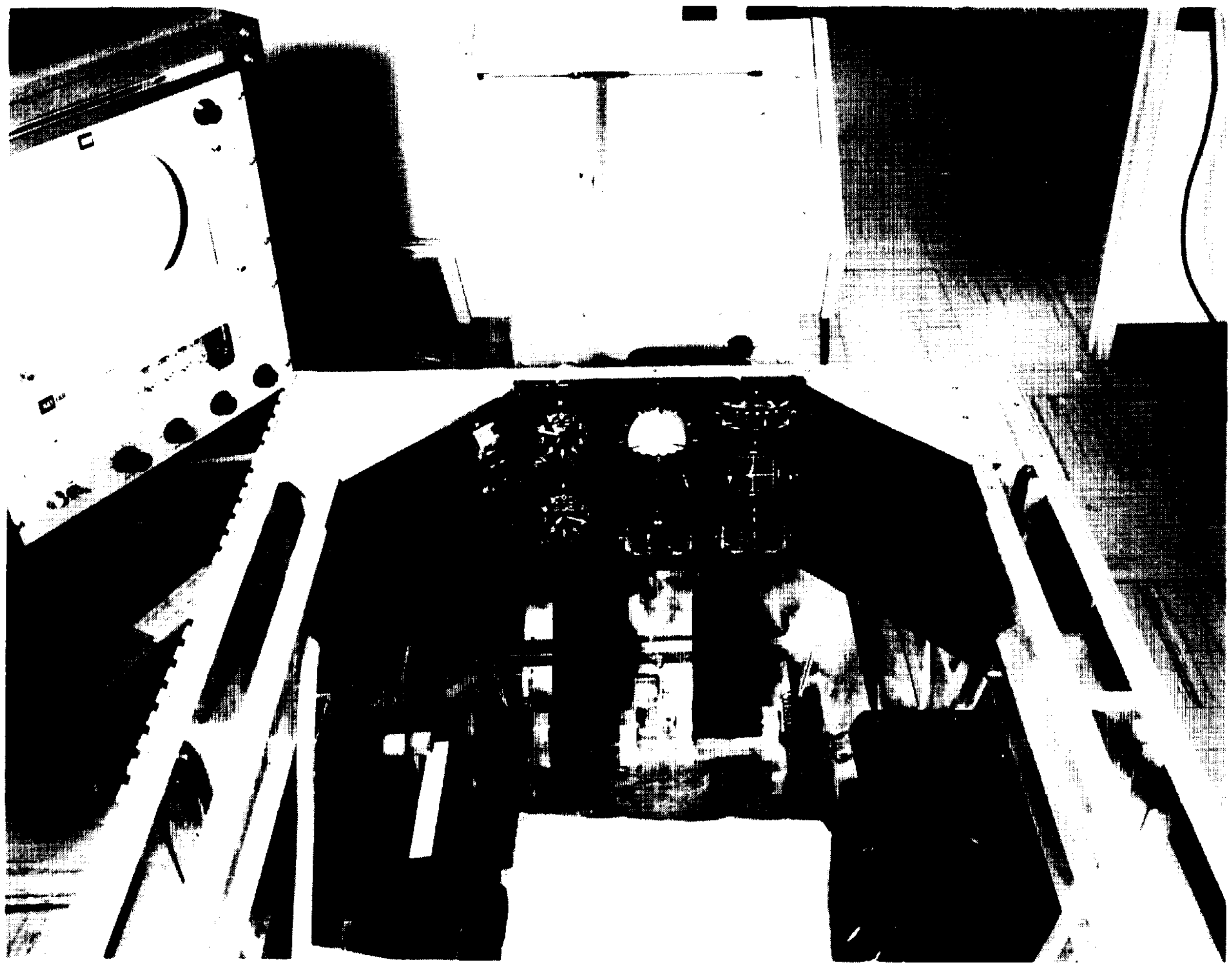


Figure 6.- Effect of thrust capability on fuel use. Landing requiring about 45° of moon's circumference. I_{sp} = 440 and 315.



(a) Instrument panel. L-61-6517

Figure 7.- Piloted lunar letdown console.

(b) Cockpit. L-61-6516

Figure 7.- Concluded.

Lunar Landing Phase

Human pilot control of a vertical landing.- To investigate (on earth) pilot control of a lunar landing, a means of supporting 5/6 of the mass must be obtained to simulate the lunar gravitational accelerations. A model servo control system is presently being built to check out a system to accomplish this. The system will be capable of supporting a man in a small (300-pound) research vehicle and with vertical descents up to 50 feet per second.

This design was made primarily as a pilot model for a full-scale research facility, but will permit preliminary research to be conducted on control effectiveness and thrust requirements for a pilot to land a rocket-powered vehicle.

An artist's drawing of the rig is shown in figure 8. Construction of this pilot model has started. Tests are contemplated to start in early spring of 1962.

Jet-blast effects during a lunar landing.- A preliminary investigation has been conducted to determine the effects of jet blast, at low ambient pressure, on a surface covered with loose particles. Tests were conducted using groups of from one to four nozzles at various cant angles and heights.

The results indicate the possibility of problems existing in this area ranging from visibility impairment to damage from impact of the surface particles with the vehicle.

A more extensive study, both theoretical and experimental, of jet-blast effects at low ambient pressure is being conducted. Both phases of the investigation utilize a single jet alined normal to a variety of ground surfaces. The theoretical and experimental studies will be compared to arrive at a scaling criterion to relate the small-scale tests to full-scale results on the lunar surface. The experimental studies will include correlary tests to determine the effect of various surface materials.

Coincident with the studies just discussed, an experimental investigation is planned to study means of minimizing jet-blast effects at low ambient pressure by use of canted multiple jets.

All of these investigations are intended to ultimately arrive at operating techniques to minimize the effects of jet blast on a lunar landing vehicle.

An artist's reproduction made from a high-speed motion picture of one of the runs is shown in figure 9.

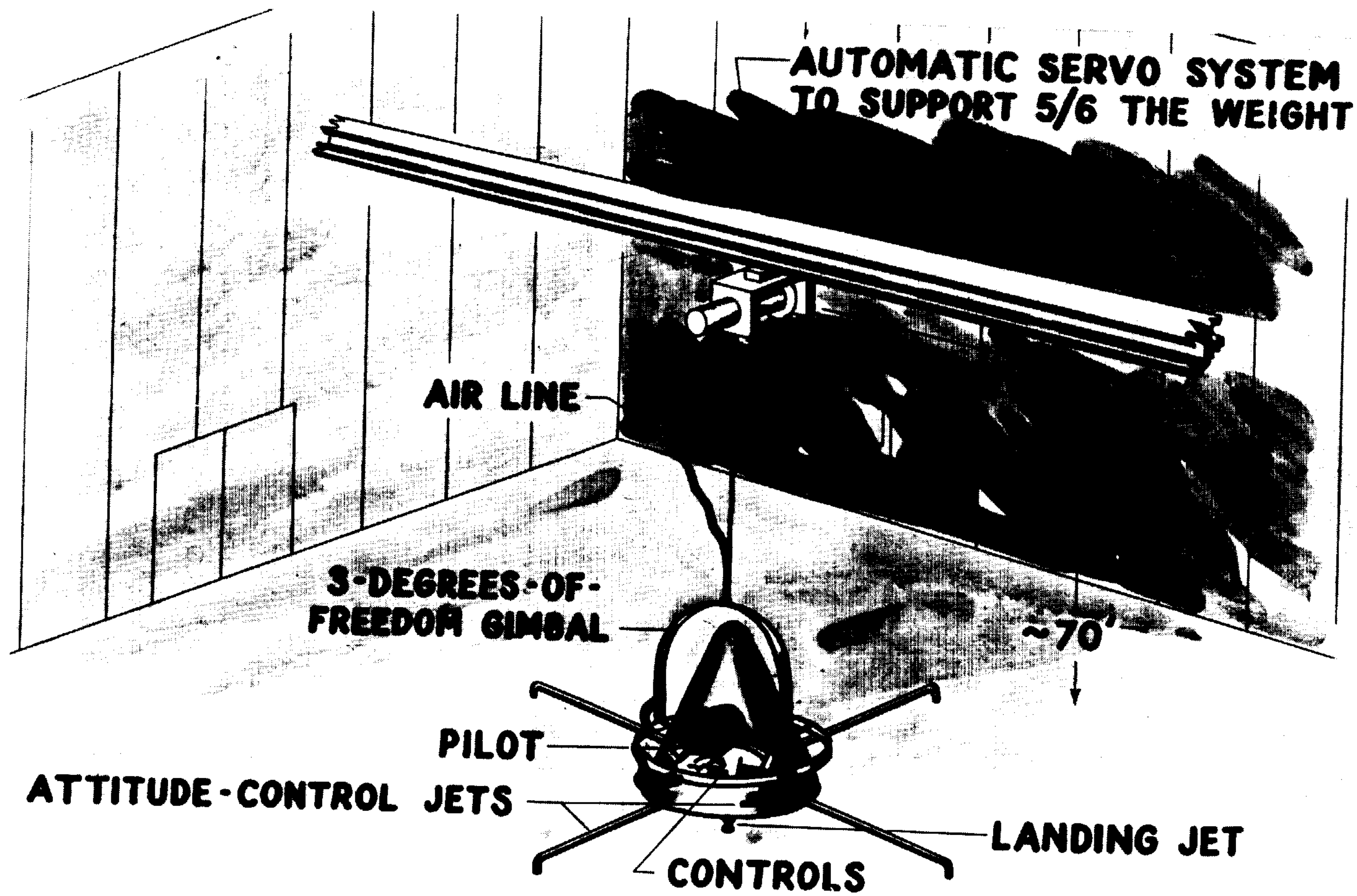


Figure 8.- Pilot model of vertical descent research facility. L-1295

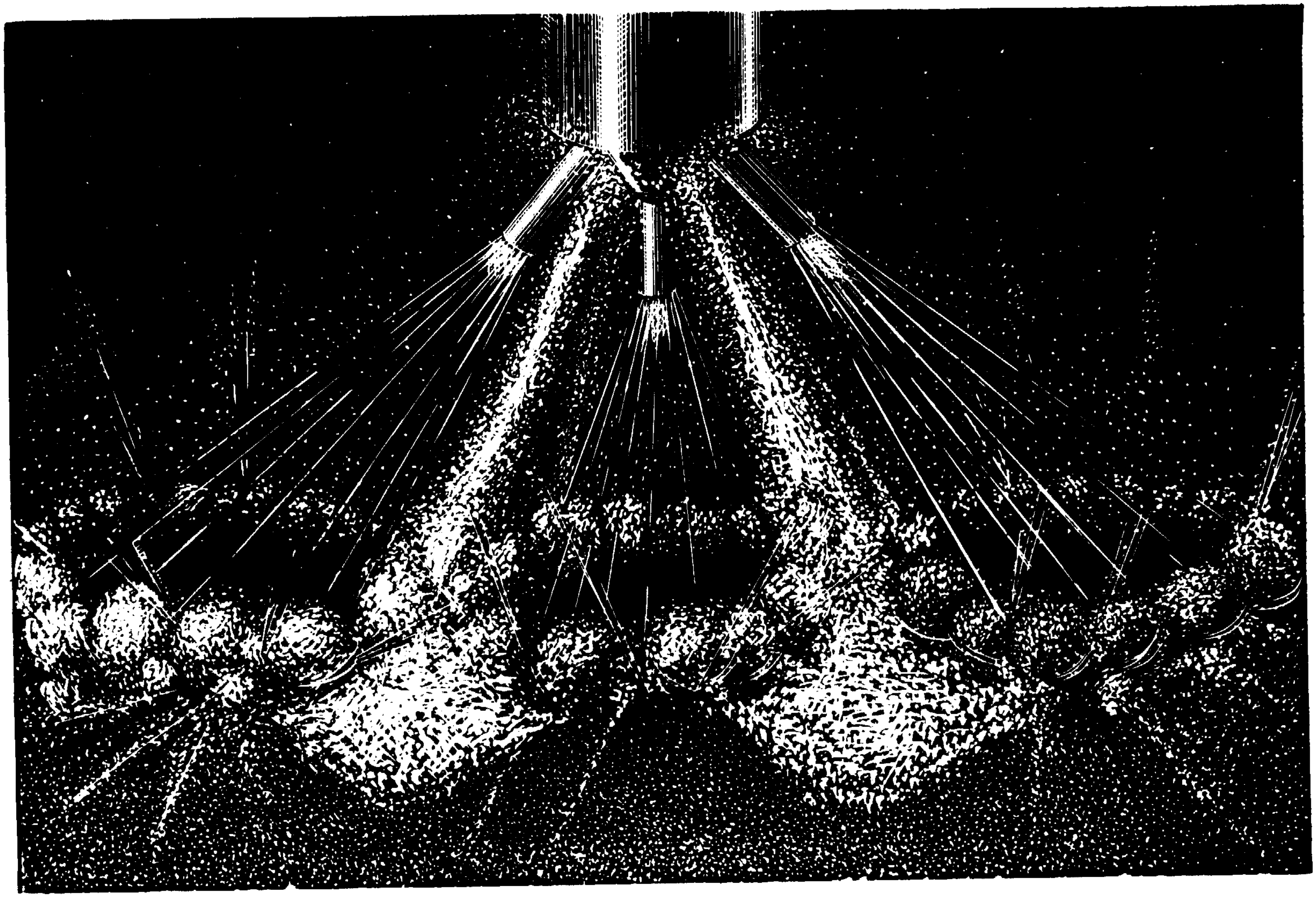


Figure 9.- Artist's reproduction of jet-blast effects.

Lunar Take-Off

Pilot control of a lunar take-off and rendezvous to a lunar orbiting station.- A simulation study of a lunar take-off, midcourse guidance, and rendezvous is to be made. This study will cover a large range of conditions such as relative positions of the vehicles at take-off, vehicle parameters, thrust levels, etc. This study will include a continuation of the abort studies described elsewhere. The pilot will utilize only visual cues for control during the initial part of the studies (instruments will be added if required).

The essential components of the simulator are shown in the composite photo of figure 10. A visual presentation of the stars and the orbiting station will be displayed by projectors. Motion cues during thrusting periods will be supplied by rotational accelerations of the 3-axis chair shown in figure 11. Motion cues during coasting periods will be supplied by a 3-axis-of-rotation projector drive unit not shown on the photo. An appropriate washout system will be incorporated to keep the pilot in a near-vertical seating position at all times.

Research is expected to begin in mid-Fall of 1961.

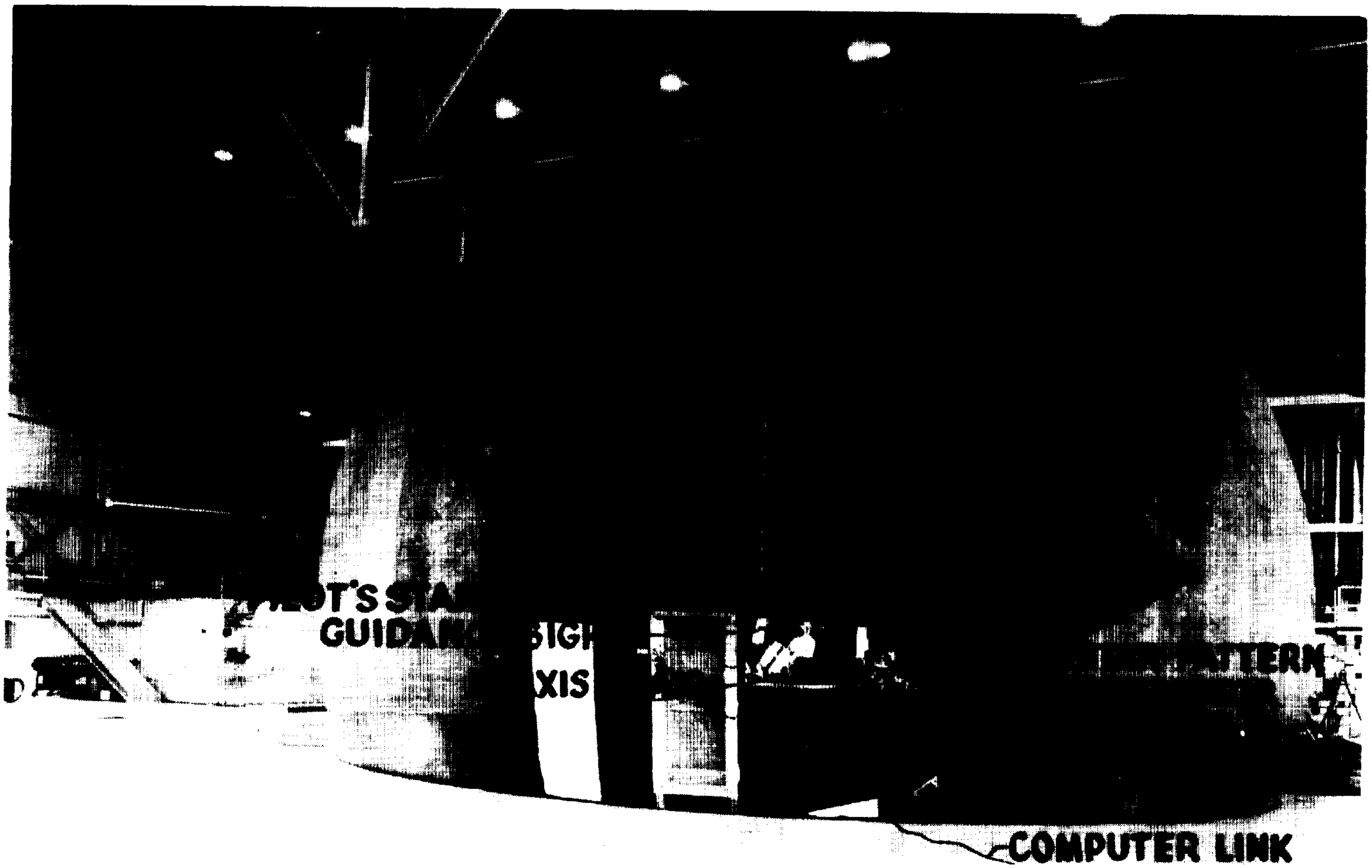


Figure 10.- Pilot-controlled lunar take-off simulator. L-1292

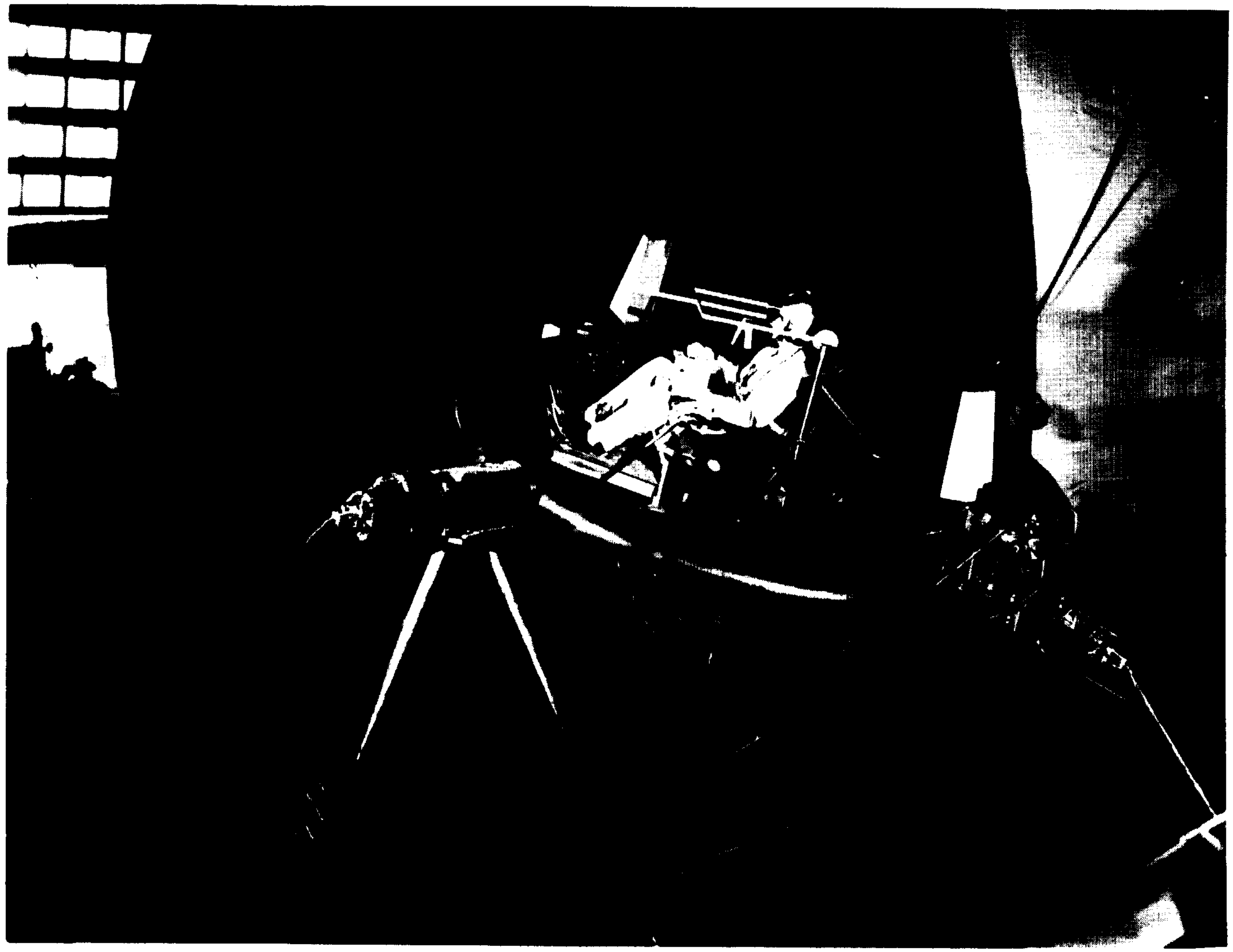


Figure 11.- Three-axis chair.

L-61-5204

Orbital Assembly

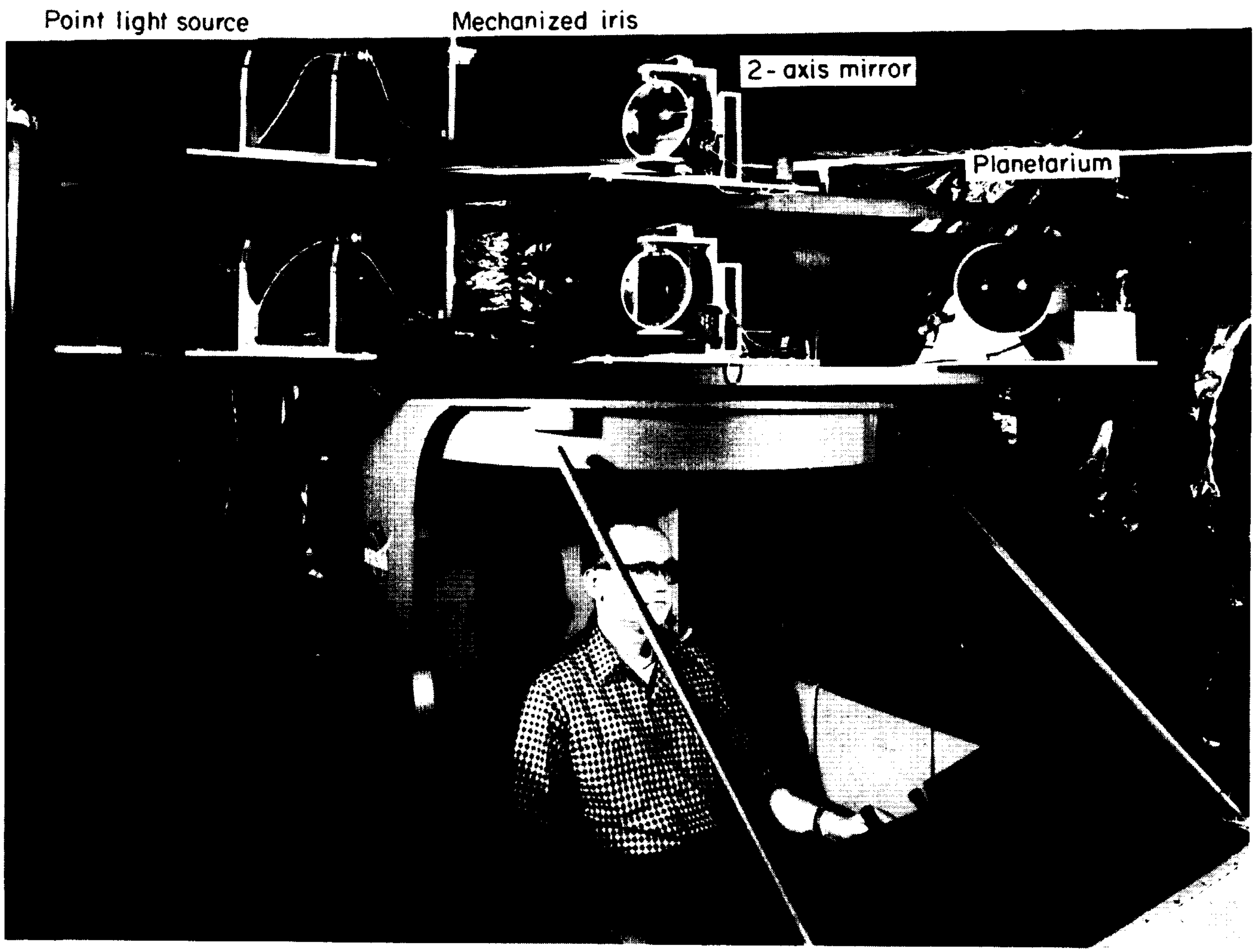
Fixed-base analog study of a pilot's performance in controlling from a distance the docking of two orbiting bodies using visual cues for guidance.- An investigation is in progress to assess a pilot's capability to perform the final docking maneuvers of two or more unmanned tanks from a remotely located manned space capsule. This fixed-base analog study primarily considers task performance by the pilot through the use of visual cues.

The results of the investigation are of interest in regard to the proposed scheme of achieving early manned lunar and interplanetary flights by utilizing the approach of constructing the final space vehicle from several payloads which are placed in near proximity and in nearly circular orbits by the use of launch vehicles now under development.

Photographs of the equipment being utilized in the investigation are shown in figure 12. The two unmanned tanks are represented by light spots which are projected on a cylindrical screen having an 8-foot radius. The projection system for each vehicle consists of a point light source, a mechanized iris which regulates the size of the light spot according to the vehicle's range, and a two-axis mirror which positions the light spot on the screen according to the equations of motion as programmed on an analog computer. Also shown in figure 12(a) are the pilot's cabin and a small planetarium used to provide a star background.

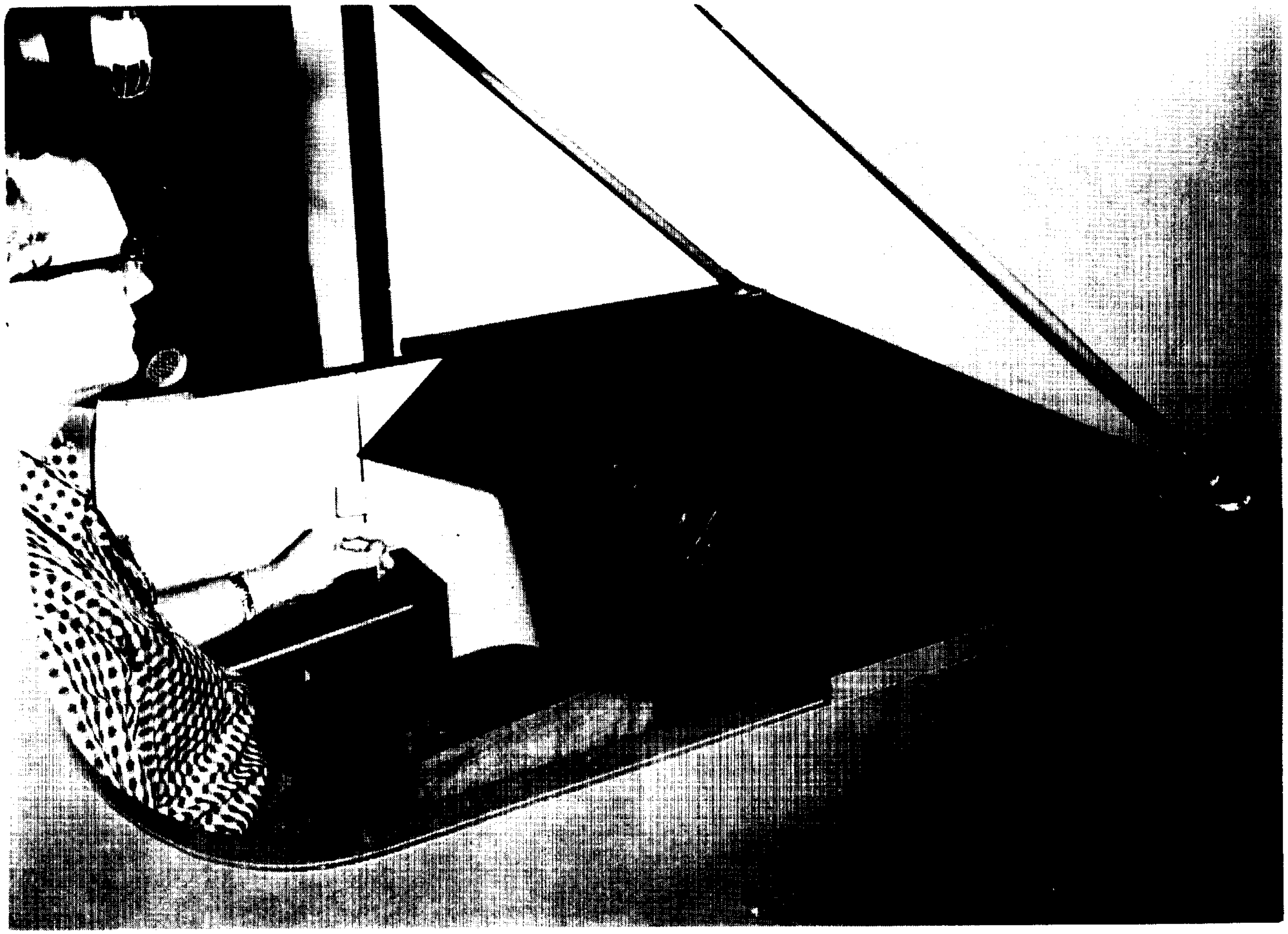
The initial conditions for this docking study consider the rendezvous maneuver to have been completed when the three vehicles are located within a 1/4-mile range of each other and to be moving with residual velocities of only a few feet a second relative to one another. The pilot is given control of his own vehicle and one unmanned tank. The task is to maneuver his own capsule and the controllable tank in such a manner that he performs the docking maneuver between the two unmanned tanks when they are located directly in front of him. Since the vehicles are all assumed attitude stabilized, the pilot controls only the translational motions of two of the vehicles. The docking maneuver is considered completed when the two light spots are located in front of the pilot, are the same size, and are tangent to each other.

Preliminary results of the investigation obtained thus far indicate that with a little practice in flying the simulator a docking maneuver can be accomplished entirely visually in about 5 to 8 minutes with contact velocities between vehicles of only several tenths of a foot a second. Based on an unmanned tank diameter of 10 feet, the above docking values were obtained with the unmanned tanks at approximately 100 to 130 feet range from the manned vehicle at initiation of the docking maneuver.



(a) Projection equipment and pilot's cabin. L-61-6513

Figure 12.- Photograph of docking simulator.



(b) Pilot's cabin and controls. L-61-6514

Figure 12.- Concluded.

NASA-Langley, 1961