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LANGLEY RESEARCH CENTER SIMULATION FACILITIES

FOR MANNED SPACE MISSIONS

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ABSTRACT

Simulators are used extensively at the NASA Research Centers to investigate the piloting problems of space vehicles. This paper presents a discussion of the mission phases under study and describes a number of simulators now in use or planned for these studies at the Langley Research Center and at other centers. These facilities will permit an examination of the problems of pilot control of earth entry, rendezvous, docking, lunar orbit establishment, lunar landing, lunar takeoff, and other phases of space missions. A brief review of Langley simulation studies in the field of human response characteristics is also presented.

INTRODUCTION

Space missions involve piloting tasks for which very little previous background of experience has been obtained and for which the opportunities to make actual manned experiments in space are still very limited. For this reason simulators are employed extensively in the NASA Centers to investigate the piloting problems of space vehicles. This paper describes a number of such facilities. These facilities are located at the Langley Research Center unless another location is mentioned. Figure 1 indicates some problems which have been investigated in space simulation and the reasons for these investigations. The most frequent type of studies are mission-directed studies which are intended to investigate the role of the human pilot in these space missions. Most of the work to date has been concerned with earth orbital missions or lunar missions. Some of the problems involved in these missions are listed in the figure. The first problem, lack of aerodynamic stability or damping, introduces the need for investigation of automatic stabilization systems and the ability of the pilot to control the vehicle in the event of failure of these systems. Unusual visual problems are encountered such as, for example, the requirement for the astronaut to detect very small angular motions of the line of sight to a vehicle during the rendezvous maneuver. Vehicle control is complicated by widely varying g fields ranging from zero g in space and one-sixth g on the lunar surface up to accelerations approaching the limit of human tolerance during reentry. In almost all space missions the control effectiveness and total impulse are seriously limited because of weight considerations.

New display and control techniques have been proposed for the critical phases of the space mission such as midcourse guidance and lunar landing. These techniques require evaluation. In addition to these mission-directed studies, basic studies have been conducted of human response characteristics. These studies are intended to develop methods of predicting the ability of the human pilot to control vehicles of various types. Also, basic studies have been made on the effect of approach to human tolerance limits of such factors as acceleration, angular motion, and fatigue and confinement on long duration missions.

ORBITAL MISSION STUDIES

The earliest interest in space missions was concerned with orbital flights either of a capsule type vehicle such as the Mercury, or of a more controllable vehicle such as the Dyna-Soar. Inasmuch as most of these investigations involve problems common to all space missions, a review of this simulation effort will be presented. References 1 to 7 describe some of these studies.

Early studies of the orbital mission, which commenced around 1958, were performed on fixed-base simulators such as the reentry simulator shown in figure 2. Simulators such as this presented the pilot with an instrument display containing information on vehicle attitude, rates, altitude, acceleration, etc. In addition, plotting boards were used to give the pilot the navigational information required to guide his vehicle to a desired landing spot. A fixed-base simulator proved adequate for the reentry guidance studies of this type because the time involved during the reentry (ten to fifteen minutes) is long enough to give the pilot adequate opportunity for interpretation of displays and application of controls.

Another problem of orbital reentry, particularly for capsule type vehicles, is the ability of the pilot to maintain control of short period motions of his craft in spite of lack of aerodynamic damping, rapidly changing oscillation period, and large decelerations approaching the limits of human tolerance. These problems were studied using the centrifuge facility of the Naval Aviation Medical Center at Johnsville, Pennsylvania. Some results of these studies are given in references 8 to 12. Figure 3 illustrates the method by which this facility was used as a simulator. Tests performed in this facility provided the first experience in operating a large servo-controlled motion simulator in a closed-loop manner in conjunction with an analog computer. When the pilot operated the controls of his vehicle the resulting accelerations provided by the centrifuge closely duplicated the linear accelerations imposed on the pilot, though the angular motions of the cab were somewhat in error. Tests performed in this facility included the ability of the pilot to control during the launch phase, control of reentry with the pilot in various positions with respect to the g field, and fundamental studies of the effect of acceleration level on the ability of the pilot to maintain control of his vehicle. These tests indicated that with proper restraint systems the pilot could retain full ability to control his vehicle up to and beyond the value of 8g which is encountered in the reentry of the ballistic vehicles such as the Mercury at small entry angles. These tests, therefore, gave considerable confidence in the use of ballistic type vehicles such as the Mercury capsule for early orbital missions. Since these early research investigations, the centrifuge simulation has been used extensively for astronaut indoctrination, selection, and training.

STUDIES RELATED TO LUNAR MISSIONS

Interest in lunar missions has led to an examination of various phases of the mission to determine which phases could be studied on simulators. Most of the remainder of this paper is concerned with simulation studies related to lunar missions.

Rendezvous

It has been shown previously that rendezvous techniques have many applications in lunar missions as well as in many more advanced missions. References 13 to 18 are accounts of simulator studies concerned with rendezvous. Rendezvous by automatic means involves reliance on complex automatic systems with little chance of completion of the mission if any of these systems should fail. If the ability of the human pilot to perform rendezvous could be adequately demonstrated, the inherent reliability of human control would greatly increase the attractiveness of this method for conducting space missions. Figure 4 shows a simulator which has been used to investigate the ability of the human pilot to control the terminal phase of rendezvous, that is, from a range of about 50 miles to a range of less than half a mile. In this simulation a star background was projected on the inside of an inflatable planetarium adapted from a Dew Line radome. The target vehicle was represented by a flashing light, the position of which was controlled by a servodriven mirror in response to signals from the analog computer. In addition, the pilot was provided with an instrument display to simulate data which might be obtained from onboard radar and from his own attitude references. The results of these tests may be summarized briefly as follows: Here again the long times involved in a typical rendezvous mission gave the pilot adequate time to make the necessary decisions and perform tasks involved in controlling his vehicle. After acquiring the target by observing the flashing light the pilot noted its motion with respect to a star background. He was able to visualize the situation rapidly and apply thrust in the desired direction to cause the target to appear to come to rest with respect to a star background. In this condition, then, the target vehicle is approaching on a constant bearing course. After establishment of this constant bearing course the pilot performed a braking maneuver in accordance with a schedule of range rate as a function of range, at the same time making necessary angular corrections to maintain the constant bearing course. This technique proved to be easy to learn and the fuel required for manual control was close to the minimum theoretically required. Later studies involved degrading the radar by simulation of radar noise, the use of very low thrust for performing the rendezvous maneuvers, and, finally, the elimination of the range and range rate signal. Even in the latter case, the pilot with the aid of optical sighting devices was able to utilize a technique to determine the range by timing the apparent angular motions of the target during thrusting periods.

Docking Simulator

A facility that has been used to determine the feasibility of manually controlled orbital assembly and docking operations is shown on figure 5. In this simulator two circular light spots are projected to represent two close objects in space as seen by a pilot in a third, nearby, vehicle. The images grow in size and move in relation to the pilot according to control inputs to the pilot's spacecraft and to one of the projected images. An analog computer is employed to solve the equations of relative motion in translation of the two projected images and the pilot's spacecraft. This simulation thus provides for the study of the assembly of two objects such as fuel tanks in space from a spacecraft a short distance away, or of the ability of a pilot to dock his own spacecraft with another vehicle.

The task of docking the two tanks generally was accomplished as follows: The pilot first maneuvered the capsule until the uncontrolled tank was directly in front of him. He then maneuvered the controlled tank toward the uncontrolled tank. To dock the tanks properly the pilot was required to maneuver the tanks until they appeared to be of equal size, and then to make the light spots tangent.

Initial results indicate that with a little practice in flying the simulator a docking maneuver can be accomplished entirely visually in about four to eight minutes with contact velocities of less than 0.5 fps between unmanned tanks of about ten feet diameter. These values were obtained with the tanks at a range of 100 to 130 feet from the manned vehicle at the completion of docking. Simple on-off acceleration controls were employed with a level of about 0.02 earth "g" or 0.65 feet per second^2.

In studying docking of the manned capsule with one tank, the same simulator with only one light spot was used. In this case a target, representing a grappling bracket in the capsule, was painted on the screen. The pilot's task was to bring the light spot into the target and make an approach so that the light spot filled the target. In this case the light spot represented the mating portion of the grappling mechanism. Results obtained thus far show that the pilots generally docked with contact velocities of less than 0.1 feet per second when control accelerations from 0.1 to 1.0 feet per second^2 were used.

Gemini Visual Docking Simulator

Another facility that is now operational is the Gemini Visual Docking Simulator (figure 6). This equipment is to be used to simulate the manually controlled docking of the Gemini with target vehicles. A closed circuit television system and an analog computer are employed. In this system a small scale model of the target vehicle having three degrees of freedom is mounted in front of a television camera. The model translates along the camera axis and rotates in response to the pilot's control inputs and the analog computer. The image of the target is transmitted by the TV system to a two-axis mirror above the Gemini pilot's head and is projected on the inside surface of a 20-foot-diameter spherical screen. Through the added action of this mirror system, all six degrees of freedom are simulated. The pilot and crewman are seated in a full-scale wooden mockup of the Gemini vehicle. A moving star field responsive to the Gemini vehicle's angular rates gives an impression of angular motion.

The docking simulation is initiated with the target about 1000 feet from the Gemini and continues until theoretical contact. This equipment is being used to study the effect of control mode (on-off or proportional controls), thrust levels, system failures, and lighting conditions on the ability of the pilot to perform the Gemini docking operation.

Many other simulator studies pertaining to lunar missions have been completed (references 19 and 20, for example) or are in progress. Generally speaking, these studies involve the use of fixed-base simulators, and although the results are of importance, a detailed description of the facilities is not felt to be of interest for the purposes of this meeting.

PLANNED SIMULATORS

Various simulation facilities to provide more realism and closer duplication of expected conditions for various phases of lunar missions are now in the planning or early construction stages. These facilities are described in this section.

Docking Facility

As a further means of studying the rendezvous docking problem, there is under construction a docking facility, a model of which is shown in figure 7. This facility employs a mockup of a full-scale spacecraft cockpit mounted in gimbals. This entire assembly is supported by a cable system attached to an overhead crane. The angular and linear motions are driven by servo systems through an analog computer. A mockup of the target vehicle is suspended near the end of the track. This facility enables simulation of the docking operation from a distance of 200 feet to actual contact. The servo system moves the spacecraft in response to control signals from the pilot in accordance with the differential equations solved by the analog computer. Six degrees of freedom are simulated in this facility. It will be used to study piloting techniques in docking and in controlling a spacecraft when hovering, during the abort of a landing and during take-off. At the time of writing, this simulator is in the final phases of construction.

Mid-Course Navigation

Studies of pilot ability to obtain basic optical measurements for guidance and navigation are to be made on a simulator at the Ames Research Center depicted in figure 8. The simulator consists of a crew compartment mounted on an air bearing which permits freedom of motion of 20 degrees in pitch and roll, and 360 degrees in yaw. Provisions are made for a three-man crew and all the displays, controls, etc., required for the simulation. An on-off cold gas system and a precision mechanical drive are available as alternate means for on-board control of the vehicle attitude. Provision will be made for various types of optical sensors which will be used during the investigation of various navigation systems. The outputs of these sensors are processed by a digital computer which computes the equations of the trajectory and causes the displayed objects to simulate the motion of the navigational bodies.

An external visual scene is shown limited to about a 25 degree portion of the sky with about 100 fixed stars. A model is used to represent the moon. Other models or projection systems will be used to represent the sun and planets as required.

Visual Lunar Let-Down Simulator

The guidance and control systems for tasks to be accomplished in a spacecraft in the vicinity of the moon should be as simple and reliable as possible. Therefore the determination of the optimum division of duties between the man and the automatic system is important. Simulator investigations can assess the man-machine capability. However, simulation of visual environment as well as spacecraft dynamics is necessary.

The lunar let-down simulator shown in figure 9 is being constructed at Langley to provide the proper visual environment in the vicinity of the moon. The pilot will be given a set of initial conditions at 200 miles altitude for a lunar approach. He will be required to establish an orbit, determine the orbit characteristics, perform descents to 200 feet altitude, and hover over a given landing point. He will use the lunar horizon and surface features in a number of ways to aid him in performing these tasks.

The simulator consists of a pilot's capsule, a closed-circuit TV complex, computer-driven cameras, and models of the lunar surface. There are four models of different scale which permit altitude coverage from 200 miles to 200 feet above the lunar surface. The models include a 20-foot-diameter sphere and three spherical segments. The four models will be arranged so that only two transport mechanisms and two closed-circuit TV camera groups will be needed to view the four models. The camera groups will be gimbaled and mounted on carriage-type transport mechanisms which give the cameras six degrees of freedom. Each TV camera group will consist of four cameras mounted so that each looks at a different portion of the model being viewed. The motion of this camera group over the model surface will stimulate the flight of an actual spacecraft. A process of switching between camera groups will be used to view the models concurrently, thus giving the pilot a continuous view of the lunar terrain as he descends. The capsule mock-up shown in figure 10 is one of the proposed methods for presenting the visual information. A capsule with four portholes strategically located is presently envisioned. The view from each porthole will correspond to the image from one of the four cameras in the TV camera group.

The capsule mock-up will include controls so that the pilot will essentially be able to "fly" the camera groups, in six degrees of freedom, through a computer which furnishes the dynamics and kinematics of the problem.

Langley Lunar Landing Research Facility

A research facility, designed to study the problem of a human pilot controlling the final phase of a lunar landing, is presently under construction at Langley. The completion date of this facility will be late 1963.

To give a realistic simulation of the lunar acceleration field, the facility will be built as indicated in figure 11. It is an overhead-crane structure about 250 feet tall and 400 feet long. The crane system is to support 5/6 of the vehicle's weight through servodriven vertical cables. The remaining 1/6 of the vehicle weight pulls the vehicle downward, simulating the lunar gravitational force. During research flights the overhead-crane system is slaved to keep the cable near vertical at all times. A gimbal system on the vehicle will permit the angular freedom needed for pitch, roll, and yaw.

The facility will be capable of testing vehicles up to 20,000 pounds in weight. The pilot will have complete six degrees of freedom in a volume of 400 feet in length, 165 feet in height, and 50 feet in width. A catapult system in the first 100 feet of the structure length will permit initial test velocities of up to 50 feet per second horizontally and 30 feet per second vertically.

A research vehicle is being constructed along with the facility. It is to be provided with a large degree of flexibility in cockpit positions, instrumentation, and control parameters to study landing problems. The vehicle will have main engines of 6000 pounds thrust capability, throttleable down to 600 pounds, and attitude jets.

Although the first task for this complete facility will be the lunar landing phase, the design is such as to permit studies of large-scale rendezvous docking, and assembly tasks.

HUMAN RESPONSE CHARACTERISTICS

The control system in a manned vehicle generally is made up of numerous mechanical and electronic components and a pilot. The characteristics of mechanical and electrical components may be replaced by mathematical equations in the simulation. The pilot characteristics which are important for control purposes (such as frequency-response, response to visual and motion stimulii, etc.) are not well known, therefore the pilot has to be used in the control system in the simulation. This fact places certain limitations on studies made with simulators. For example, judgment of the difficulty, or quantative measurement of accomplishment is difficult in a task when the primary judgment is based on pilot opinion.

These considerations indicate the desirability of attempting to determine the basic control characteristics of a pilot. This problem, of course, has been recognized and studied over a period of time (see references 21-24, for example). Work in this area is being continued at various laboratories, but progress has been slow because of the time required to evaluate the characteristics of the pilot. A study is currently in progress at the Langley Research Center of a procedure for determining the pilot transfer function during the course of a test. A block diagram of the situation is shown in figure 12. The pilot is presented with a single degree of freedom tracking task displayed on an oscilloscope, and his control is a stick which produces a control signal proportional to stick deflection. The control loop is completed by inserting controlled systems of different order dynamics between the stick output and the display. The analog pilot output is made to match, as closely as possible, the pilot's stick output by automatically adjusting three variable gains in the analog pilot. The results of the tests are sets of gains that vary for each of the different simulated dynamics, with lesser variations from pilot to pilot, or for the same pilot on different days. These results are given in reference 25.

It is hoped that further testing will lead to an understanding that is adequate to allow these measurements to be used in evaluating system design concepts, and perhaps, to allow the use of the analog pilot as a substitute for the pilot in design studies.

Concluding Remarks

A review of the space simulation facilities at the Langley Research Center has been presented to show the range of problems investigated and the new simulators being prepared for future studies. The work accomplished on these facilities has shown the importance of simple fixed-base simulators, operating in conjunction with general purpose analog computers, in obtaining basic information for the planning of manned space missions. Detailed studies of the various phases of these missions require more complex equipment involving motion cues and visual displays. These simulators will contribute to the development of techniques and equipment to allow the most effective combination of manual and automatic control for performing the missions.

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SPACE SIMULATION PROJECTS

MISSION – DIRECTED STUDIES
  EARTH ORBITAL MISSION
  LUNAR MISSION

    PROBLEMS:
      LACK OF AERODYNAMIC STABILITY AND DAMPING
      UNUSUAL VISUAL CONDITIONS
      UNUSUAL G FIELDS
      LIMITED CONTROL EFFECTIVENESS OR IMPULSE
      NEW DISPLAY AND CONTROL TECHNIQUES

BASIC STUDIES
  HUMAN RESPONSE
  APPROACH TO HUMAN TOLERANCE LIMITS

Figure 1.- Space Simulation projects.

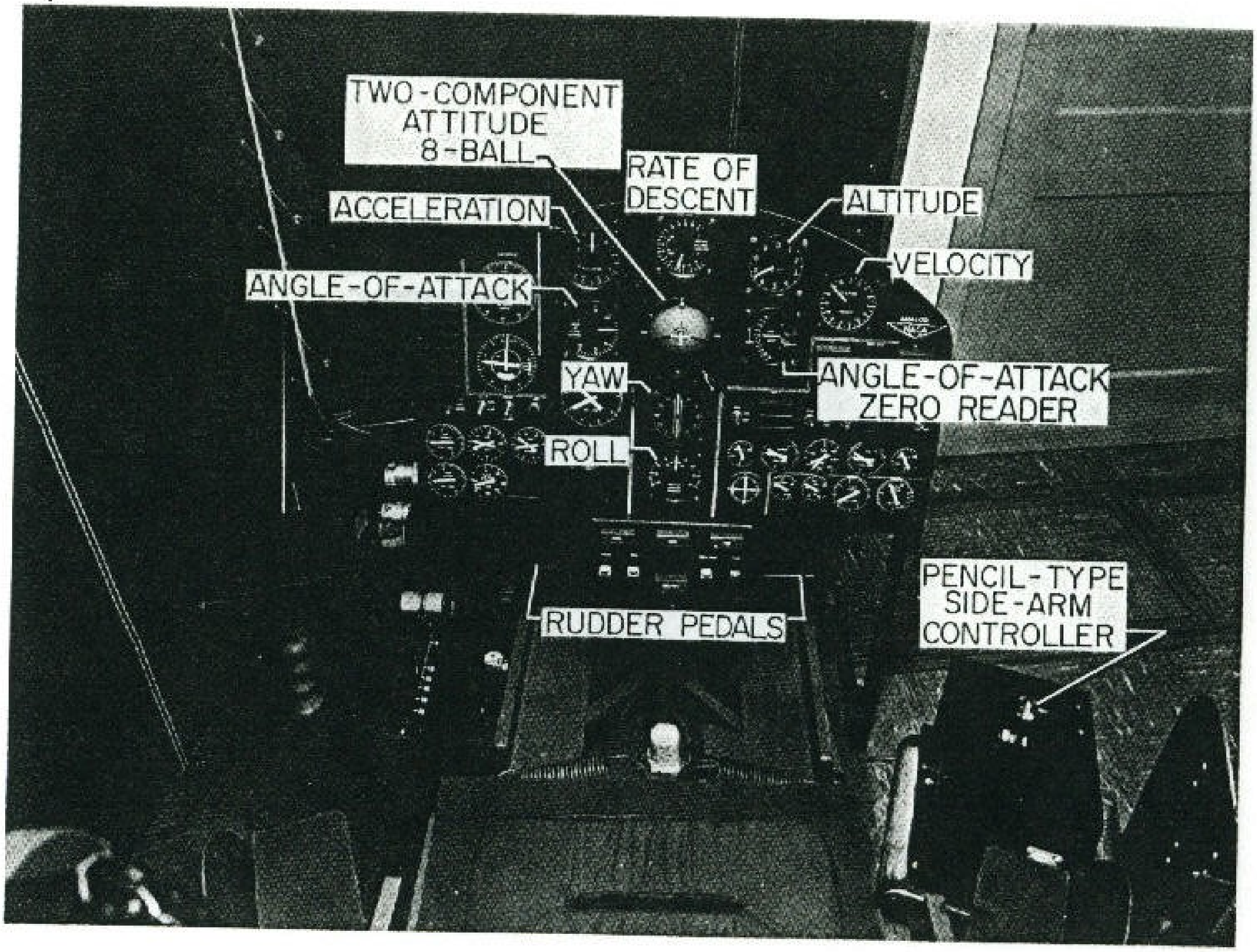

Figure 2.- Typical fixed-base research simulator.

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Figure 2.- Typical fixed-base research simulator. L-59-234.1

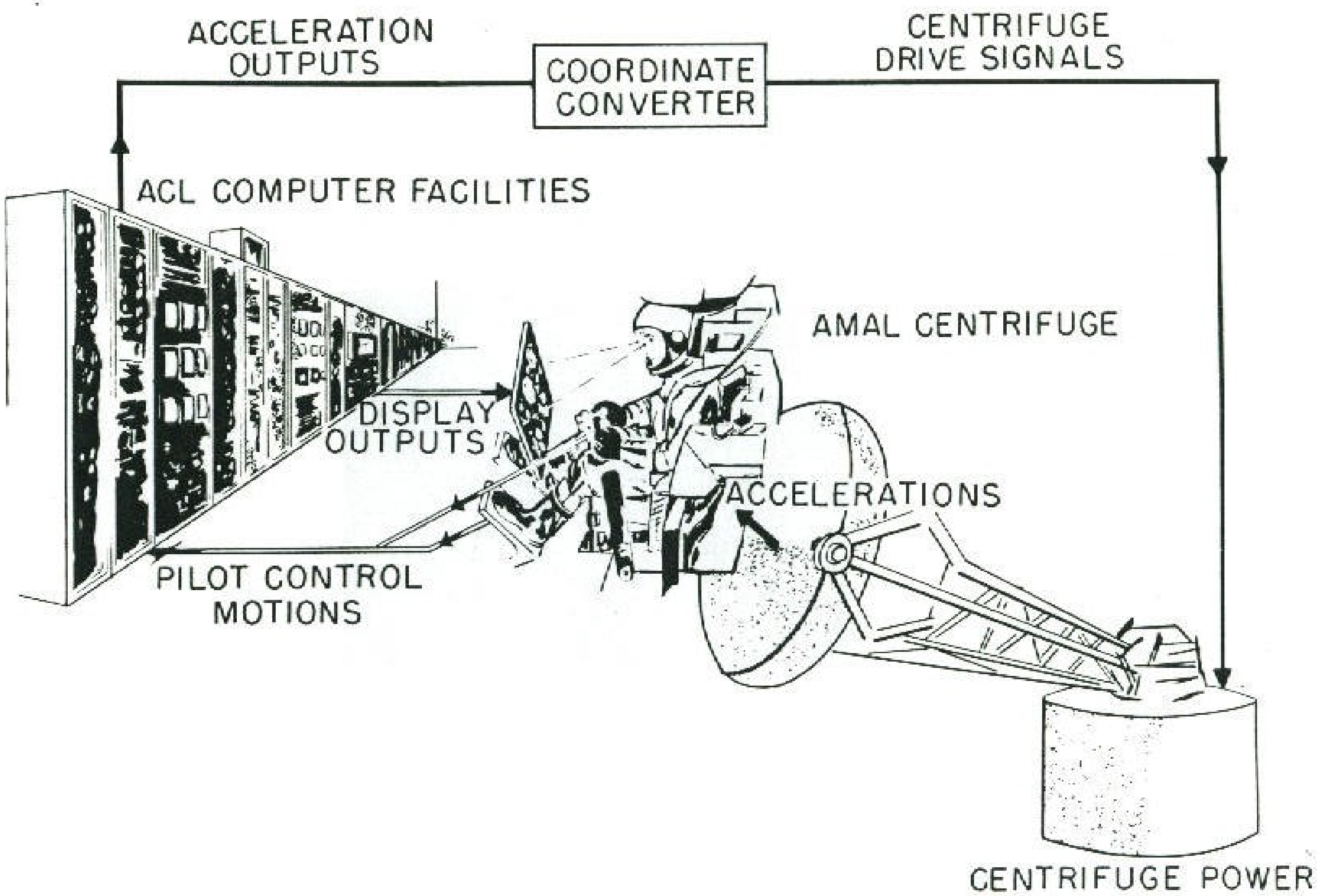

Figure 3.- Centrifuge pilot-controlled flight simulator.

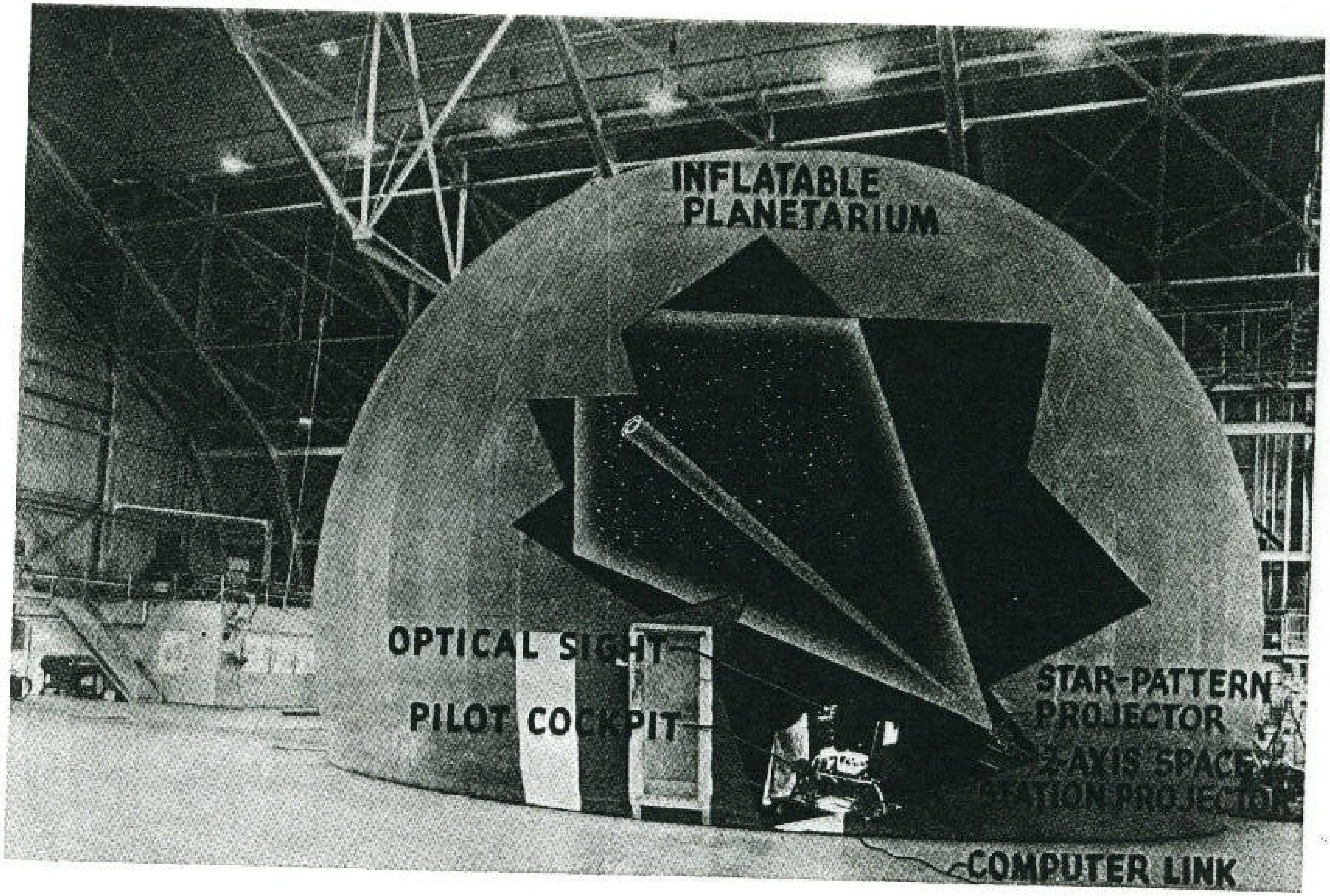

Figure 4.- Visual-rendezvous simulation equipment.

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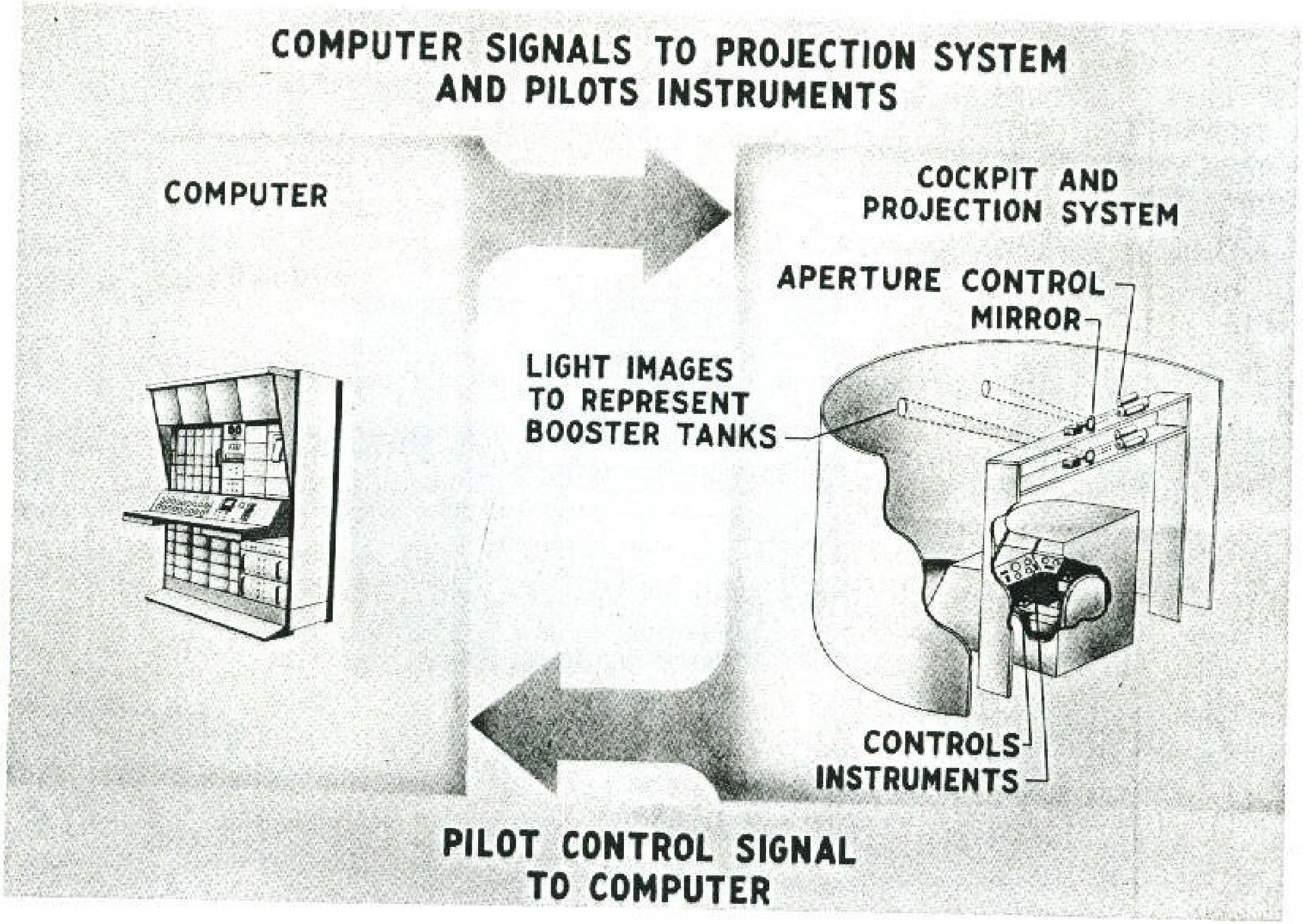

Figure 5.- Simulator for visual control of orbital assembly and docking.

NASA
L-1342

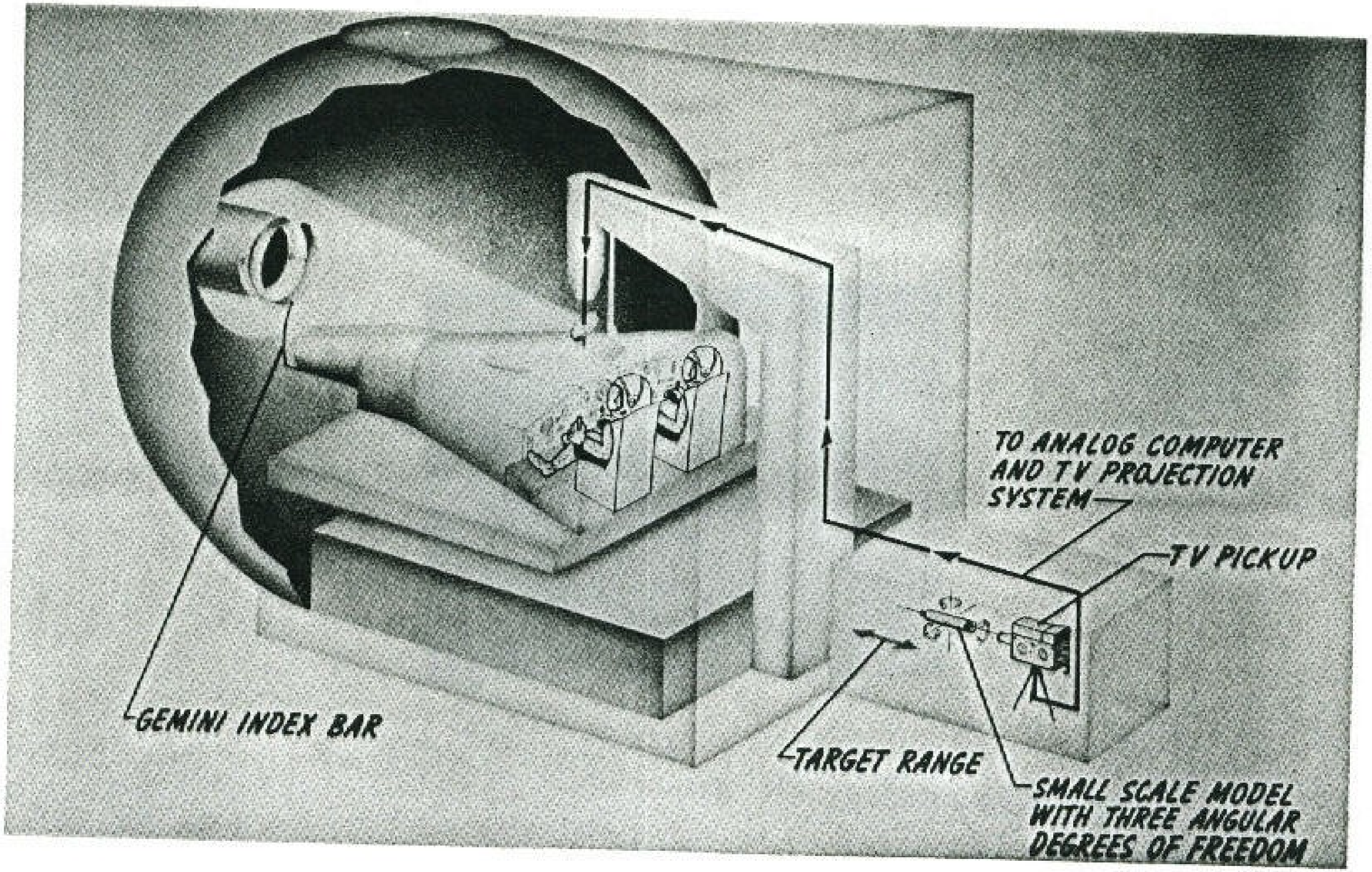

Figure 6.- Visual docking simulator.

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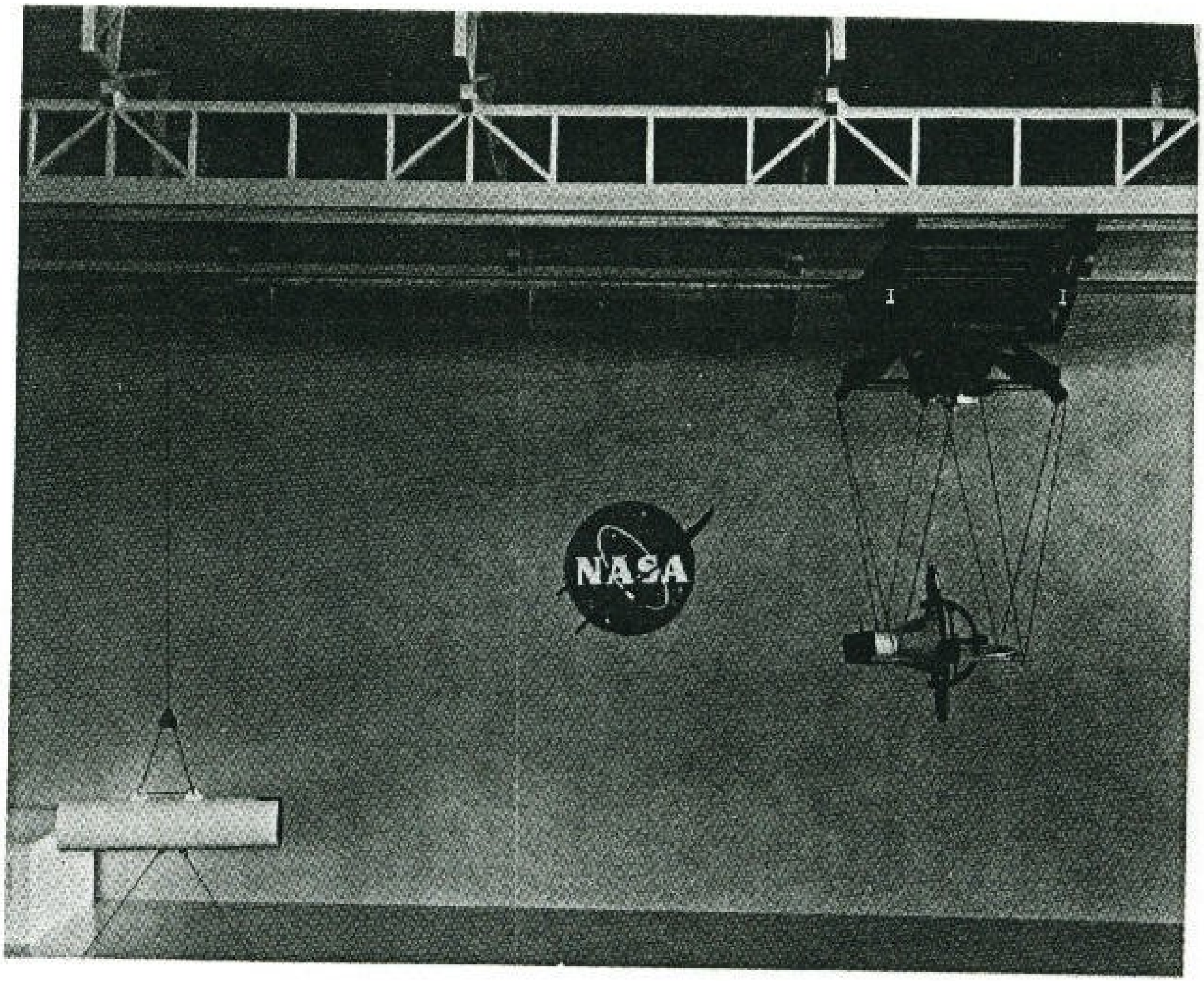

Figure 7.- Docking facility.

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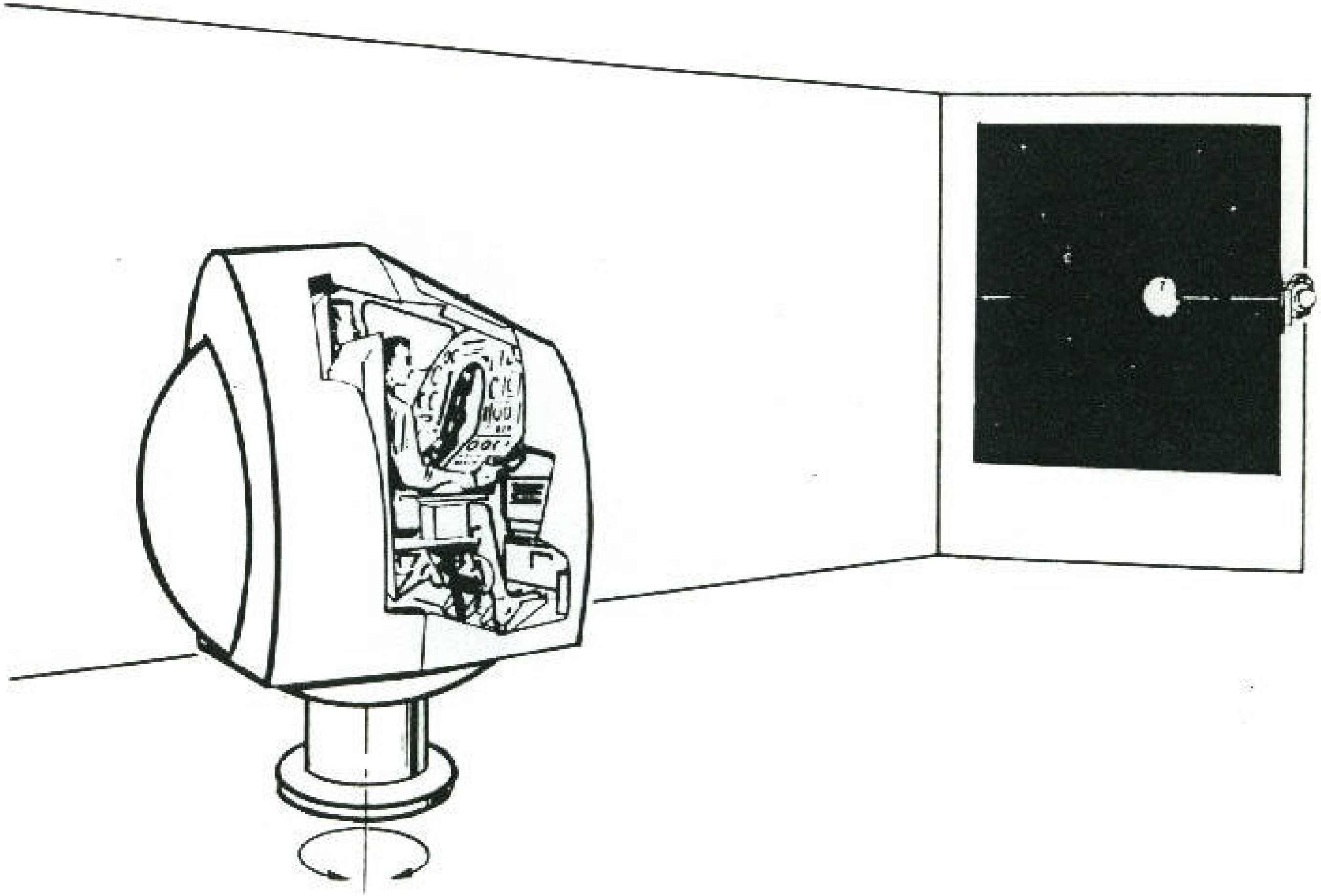

Figure 8.- Interim midcourse simulator.

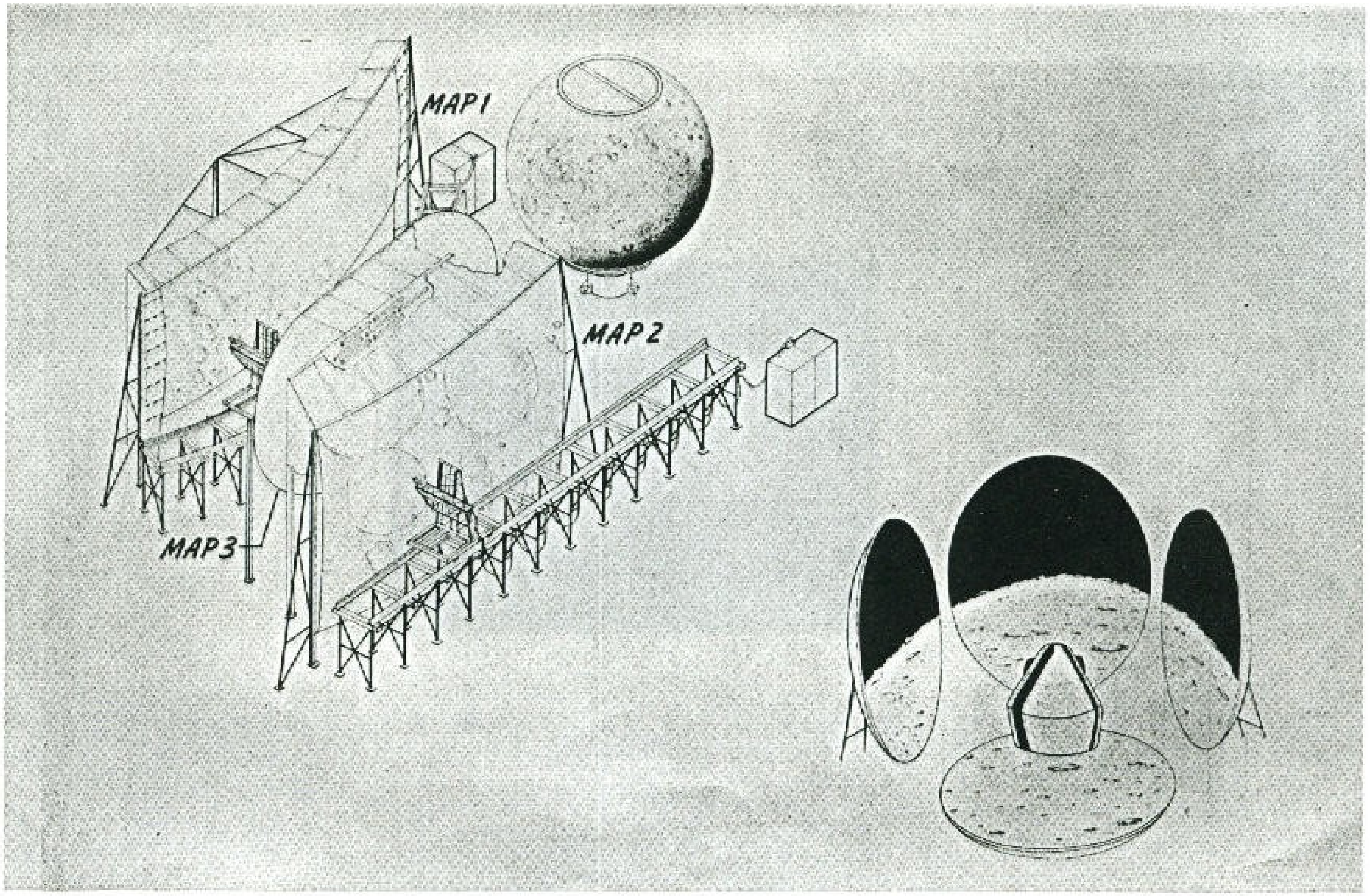

Figure 9.- Lunar letdown simulator.

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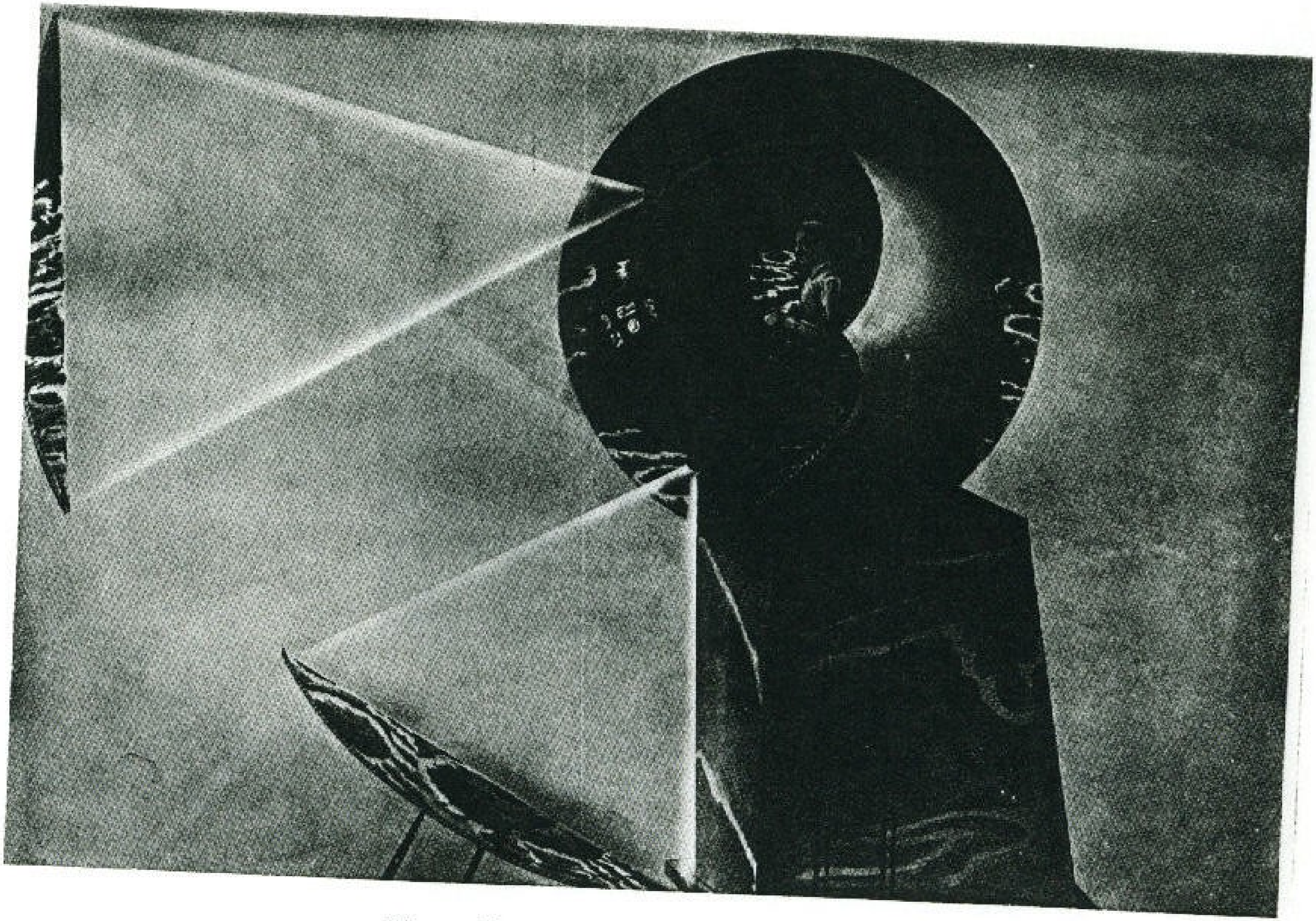


Figure 10.- Simulator projection scheme.

NASA
L-1429

Figure 10.- Simulator projection scheme. NASA L-1429

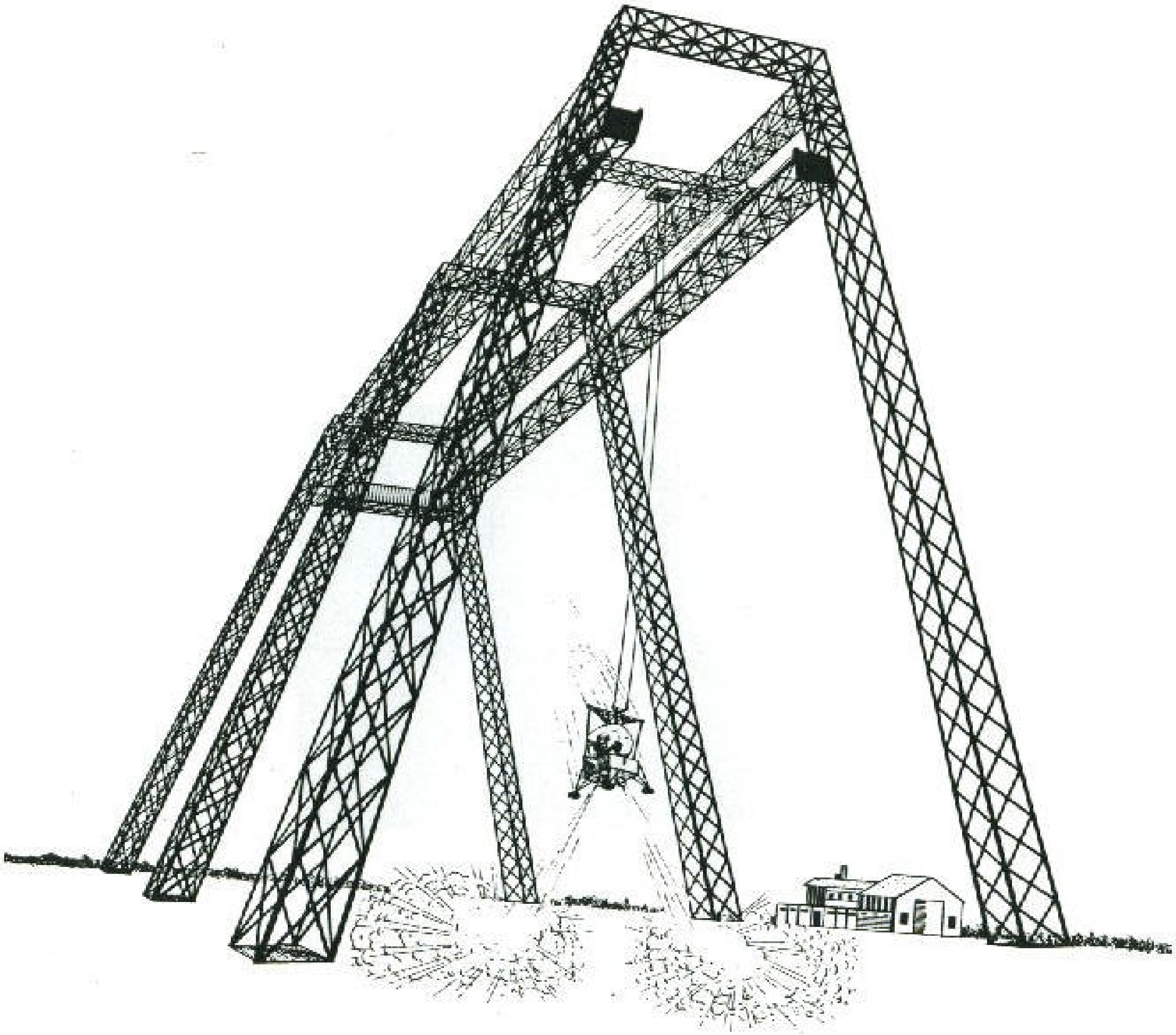
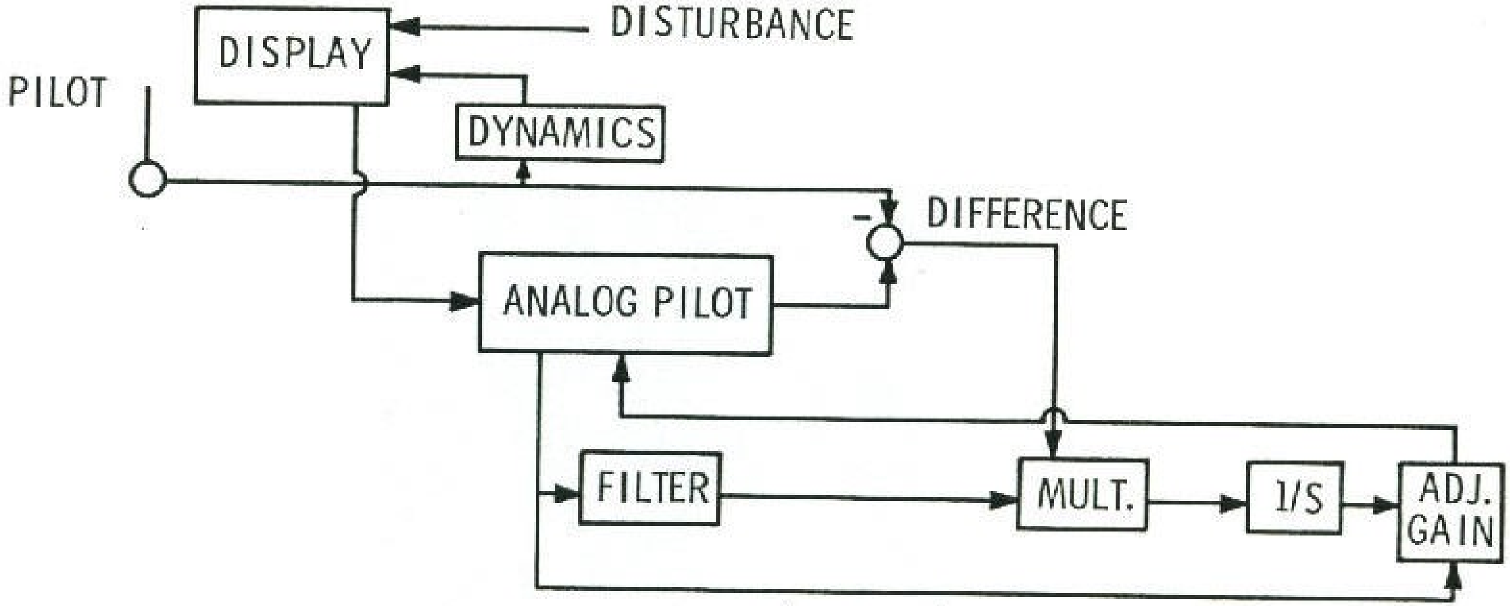


Figure 11.- Langley lunar landing research facility. NASA L-62-1010.1



$$\text{ANALOG PILOT FORM, } \frac{K_1\tau\left(1 + \frac{K_2}{\tau}S\right)}{(\tau + S)^2}$$

Figure 12.- Block diagram of test equipment for human response studies.