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The best way of investigating many piloting tasks is through the use of simulators which duplicate the mission as closely as possible. NASA Research Centers use such simulators extensively because: (1) all flight parameters can be continuously recorded, (2) parameters can be varied from flight to flight, (3) simulated flights can be repeated as many times as desired. Much of Langley's simulation work is devoted to investigating techniques which make maximum use of man's capabilities, thereby tending to minimize system requirements and increase the probability of mission success.

This paper presents a summary of Langley Research Center simulation work relating to the rendezvous and docking of two vehicles in space. Current simulators, studies conducted, and visual problems encountered will be discussed.

Rendezvous can generally be defined as bringing two vehicles together in space. The visual rendezvous technique, illustrated in the first figure and described in reference 1 utilizes the pilot's capabilities not only to control the vehicle, but also to sense and process the required information. In the visual rendezvous the pilot must first visually acquire (or detect) the target. References 2 and 3 study these visual aspects.

Directly after acquisition, an interception course is attained by arresting the angular motion of the line of sight as seen as the motion of the target against the star background, used as an inertial reference. Once the intercept course has been established the braking operation is begun and continues until the range is a few hundred feet, or less, where the docking operation begins.

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The acquisition phase of the rendezvous has come to mean detecting a flashing light mounted on the target, at night. Two high-intensity flashing lights mounted on the Agena will enable it to be detected by the Gemini pilots at ranges up to 20 miles. However, such a flashing light can only be used at night and the power requirements are relatively high. Another technique, currently being studied at Langley uses optical filtering for detection of a sunlit target. By successively viewing the search area through first a filter which transmits both the background and target, and then viewing the area through a complementary color filter which transmits the background but reflects the target luminance, the target would appear to blink against a steady background, which would greatly enhance the target.

Experimental results showed that subjects could detect the target when it was as bright as a 4th to 5th magnitude star. This means that the filtering technique does not change the threshold of detection, but using solar illumination the target could be detected at considerably greater ranges than would be possible using artificial lighting. Research is underway to find suitable coatings and filter combinations which could be used on a manned space vehicle.

Coplanar rendezvous closure control was investigated as early as 1960 (ref. 4) assuming a generalized spacecraft configuration and a simple visual display. Non-coplanar simulations of visual and instrumented displays are described in references 1 and 5, respectively. The results of this simulation work played a large part in defining man's part in the Gemini rendezvous, and also was a strong point for adopting the Lunar Orbit Rendezvous technique for the Apollo mission. Studies of rendezvous with low thrust levels, such as reported in reference 6, as well as effects of display resolution (ref. 7) also provided design information important to Gemini.

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A new simulation using Gemini control parameters is currently underway. The simulator is located inside a 53-foot-diameter inflatable radome (fig. 2) which serves as a planetarium. A star background, target reference, and earth horizon are projected on the walls of the radome.

The simulator (fig. 2) consists of a static cockpit linked through an analog computer to a modified Nike antenna drive unit which contains star background, target, and horizon projectors driven dynamically to produce the Gemini's visual environment. The simulator drives the star background in response to a Gemini rotation, superimposes the target against the star background, and drives the target against the background with proper line-of-sight rate. The pilot's ability to detect the target's motion against the star background, which is very small in the Gemini program, is an important factor in completing a successful visual rendezvous.

One problem was encountered in this simulation. When the bright target spot moved near a dim star the star sometimes disappeared and the pilot would lose his reference for determining line-of-sight rate. This effect is currently being investigated further.

The docking phase of the mission takes place from a few hundred feet in to zero range. One of the first simulators to study general pilot docking (fig. 3) utilized two circular light spots projected on a cylindrical screen to simulate remote assembly of two objects, such as fuel tanks, controlled from a spacecraft a short distance away. Reference 8 describes this study effort. An analog computer commanded the images to grow in size or to move relative to each other in response to the pilot's control inputs. This simulation showed that pilots could accurately control the docking or latching using only visual information and with a wide range of control levels.

Since this early work showed that the pilot could serve as a sensor with sufficient accuracy for visual docking control, two more elaborate simulators have been constructed at Langley to simulate the Gemini-Agena docking with high fidelity.

The first, shown in figure 4, is called the Visual Docking Simulator (VDS). It can simulate the docking from ranges up to 300 feet. 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.

I would like to discuss two of the studies made using the Visual Docking Simulator. The first investigated the effects of control modes (direct command and rate command) on the pilot's control of docking. The second was a series of flights made under daytime and nighttime lighting conditions to determine any docking problems arising from the target lighting.

The results of the first study showed that it was easier to control the docking in the rate command mode than in the direct mode. This was expected because in the rate command mode when the controller was returned to zero unwanted angular rates are automatically damped out, while in the direct command mode the pilot must provide his own damping by applying a manual control input to bring the attitude rates to zero. Somewhat surprisingly, the study showed that the reason the direct mode was more difficult to control was not because the pilot could not make precise corrections, but rather because the pilot could not distinguish between the attitude rates and the translational rates.

The pilot determined the capsule's attitude in the VDS by looking at the nose position relative to the target. Translation cues were obtained from the aspect of the target. The second study which compared the docking under day-time and nighttime lighting conditions showed that it was difficult to determine precisely the Gemini's attitude and translation errors during the day, but it was considerably more difficult at night for two reasons. First, only the cone was illuminated, rather than the entire body of the target. Second, the nose of the Gemini was not lit, so the pilot saw the indexing bar only when it was silhouetted against the illuminated target cone. Thus, the pilot had to use the cone itself, rather than the body of the target for the orientation cues, and the lack of aspect made the problem, in effect, one of docking with a two-dimensional rather than three-dimensional target. Since the pilots could not determine the vehicle alignment, then they concentrated on just flying the indexing bar into the docking slot. As a result the pilots positioned the indexing bars slightly (about an inch) more accurately at night, but only with a sacrifice in vehicle alignment.

The next logical step was to look for a visual aid technique which could be added to the Gemini/Agena without a major modification, and which could reduce the inaccuracies and increase the pilot's confidence, particularly in the darkside (night) docking. Several visual aids were tested using both the VDS and the RDS, the Rendezvous Docking Simulator.

The Rendezvous Docking Simulator (fig. 5) involves a full-size model of the cabin and nose sections of the Gemini spacecraft, associated drive systems, a general-purpose analog computer, and a full-size lightweight model of the Agena target. The Gemini capsule is mounted in a hydraulically driven gimbal system which provides three degrees of attitude freedom. The entire capsule and gimbal system is, in turn, mounted on a horseshoe-shaped box frame which is suspended by eight cables from an overhead bridge-crane system. The electrically driven bridge-crane provides three degrees of translational freedom. The analog computer commands the drive systems to move the capsule in response to the pilot's control inputs, just as though the capsule were the Gemini vehicle in space. The RDS can simulate the docking from ranges up to 150 feet and permits studies using the actual Gemini and Agena hardware.

I would like to discuss two of the studies made using the RDS. The first was an evaluation of the suitability of the Agena Target Docking Adapter, or TDA. The second was an investigation of the effect of thruster failure on the pilot's control of docking.

For the first study McDonnell supplied the hardware mockup of the Agena Target Docking Assembly for use in an investigation of possible problems in docking using the TDA and an optimization of the Agena's visual aids.

The TDA is shown in figure 6. In addition to the docking cone and latching mechanism it contains two high-intensity flashing lights mounted at about 11 o'clock and 5 o'clock on the Adapter. These lights will enable the astronauts to detect the Agena at ranges up to 20 miles. The lights will be turned off at 500 feet in order not to distract or blind the pilot. Pilots made part of these simulated flights with these lights on in order to determine to what extent the docking would be degraded if the lights did not turn off. Pilots agreed that the lights were distracting and reduced the pilot's confidence, but they felt that they could dock successfully, particularly if the lights could be repositioned on the target. If the lights were placed at 9 o'clock and 3 o'clock they would not be seen by either astronaut when docked.

As mentioned earlier, the night flights had shown a need for a visual aid technique which could increase the docking accuracy. Two types of aids were indicated. The first aid would be a light to illuminate the nose of the Gemini so the pilot could determine the vehicle's attitude. A floodlight mounted on the capsule to illuminate the nose was tried and found to be satisfactory. The second aid would be mounted on the target and would provide a reference for aligning the axes of the capsule and target. Three aids were tested on the Target Docking Adapter. The first was a probe projecting out of the TDA along the pilot's line of sight. The second aid was a 30-inch square with lights at three corners, mounted near the rear of the target. A light near the front of the target completed the square when the vehicles were aligned. The third aid tested was illuminated vertical and horizontal bars mounted front and back on the target. All the pilots who flew the simulator, including four astronauts, agreed that the bar aids were better.

Another study using the RDS investigated the effects of jet failure on the pilot's ability to complete the docking. The case in which a control jet failed to fire was simulated. If a jet were to fail open (not turn off), the astronaut could cut off the fuel to that particular jet and then the situation would be the same as that simulated. Vertical and lateral jet failures were the most difficult to control because these fire singly. All other jets fire in pairs, so if, for example, a braking jet failed to fire it would only cut the control power in half. If a vertical jet failed to fire, however, the capsule just could not move unless the pilot either rolled and fired a lateral jet, or pitched and fired a longitudinal jet. Only these most critical malfunctions were studied and techniques developed for overcoming them successfully.

This gives an example of some of the simulation work at Langley related to rendezvous and docking. Other studies made with the simulators include: (1) technique for manually determining range and range rate during rendezvous, (2) evaluation of the Gemini cockpit instruments and controllers, (3) techniques for reducing control cross-coupling by canting the translation jets, and (4) remote controlled docking using closed-circuit television.

The Visual Docking and Rendezvous Docking Simulators are excellent examples of closed-circuit television and dynamic simulators. Each has inherent advantages and disadvantages. Closed-circuit television permits simulating relatively high velocities and longer ranges, and it is relatively easy to vary the lighting conditions, but the picture loses fidelity at close ranges and the minimum range is determined by the distance from the observer to the projection screen. The dynamic simulator gives the pilot the same view he would have from the spacecraft including target aspect, and permits closure to vehicle contact, but it is difficult to eliminate visual cues. We do so with flat black curtains to keep ambient light out of the darkened hangar, and by using filters over the capsule windows. Thus it is necessary to consider not only the pilot's visual capabilities, but also the simulator's visual characteristics.

All of the simulators discussed are used for research rather than training, so they are designed to be versatile. This permits investigating many problems with one piece of equipment. For instance, the rendezvous simulator will also be used to study the lunar take-off phase of the Apollo mission, the Visual Docking Simulator will be used to study space station docking, and the Rendezvous Docking Simulator can conduct lunar landing studies.

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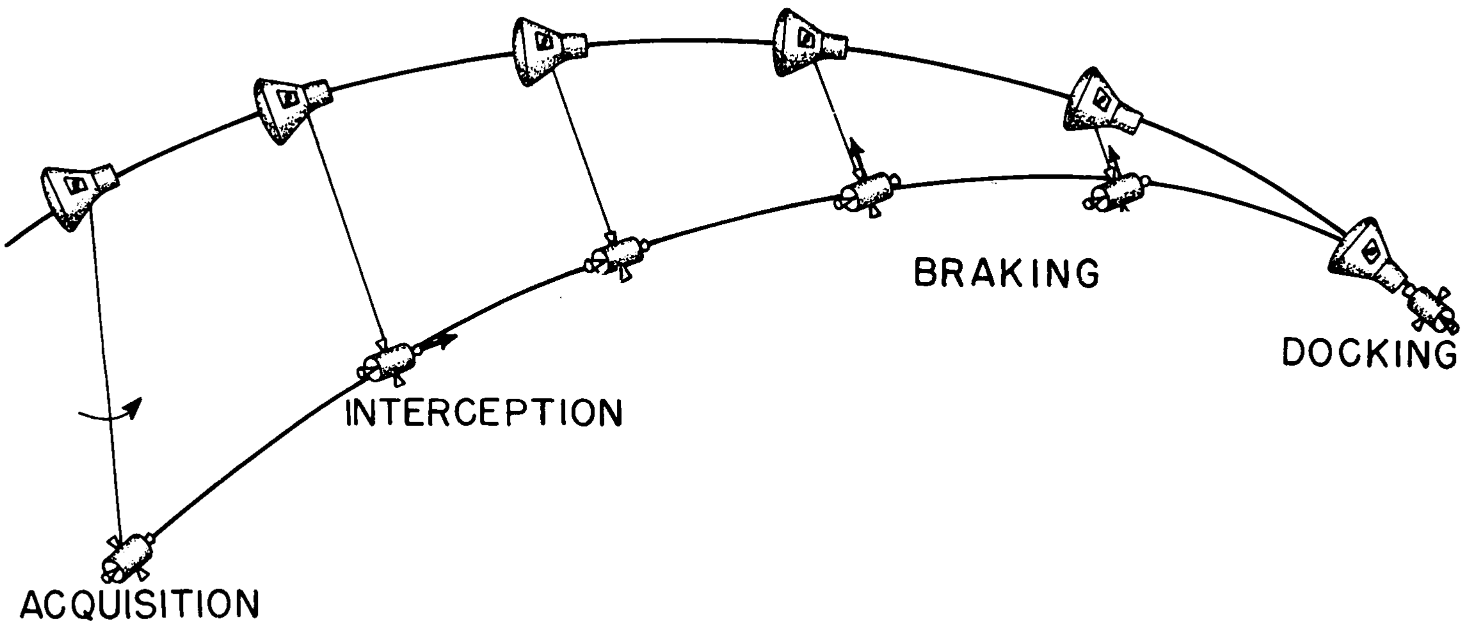

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Figure 1.- Phases of visual rendezvous.

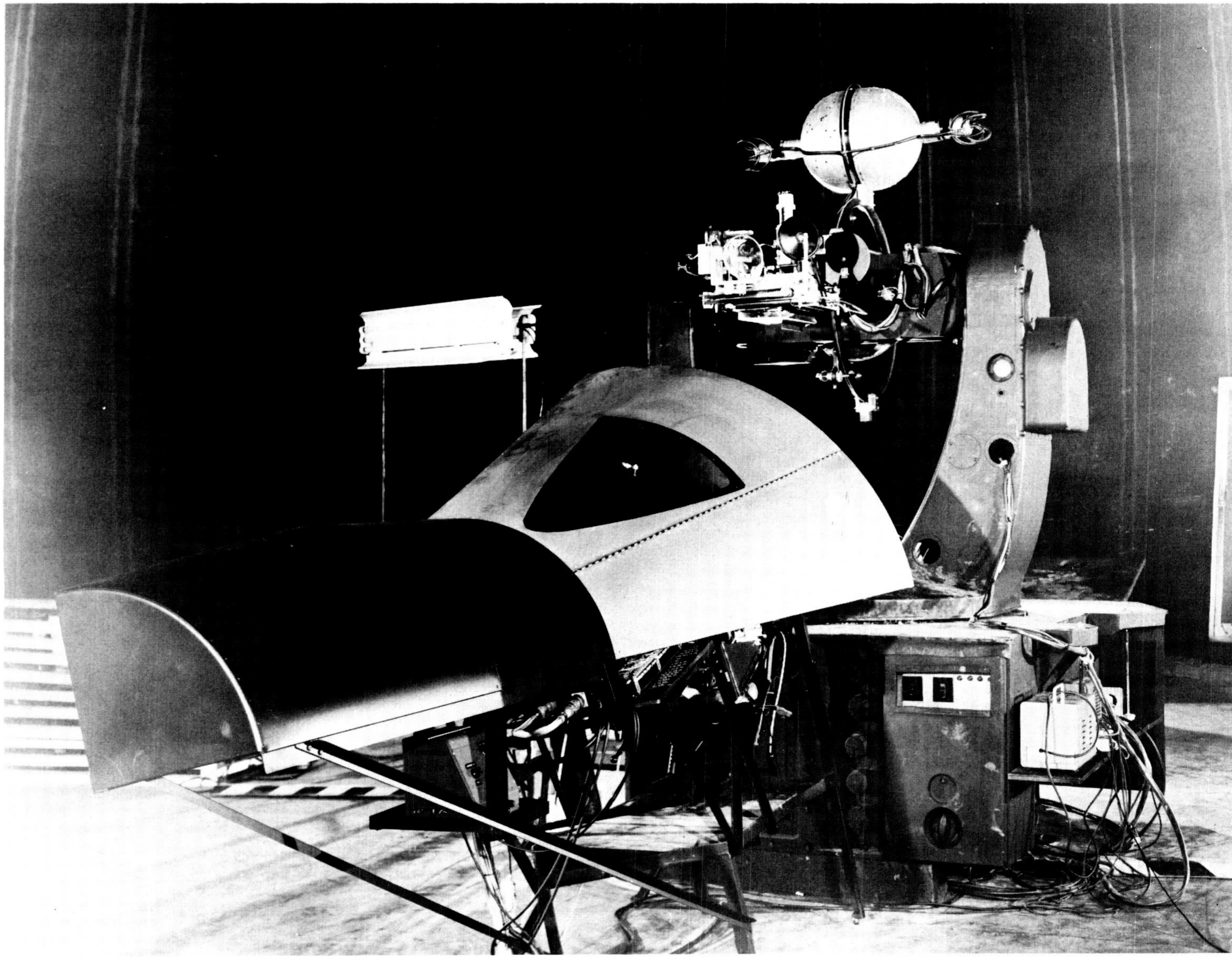

Figure 2.- Gemini simulation equipment.

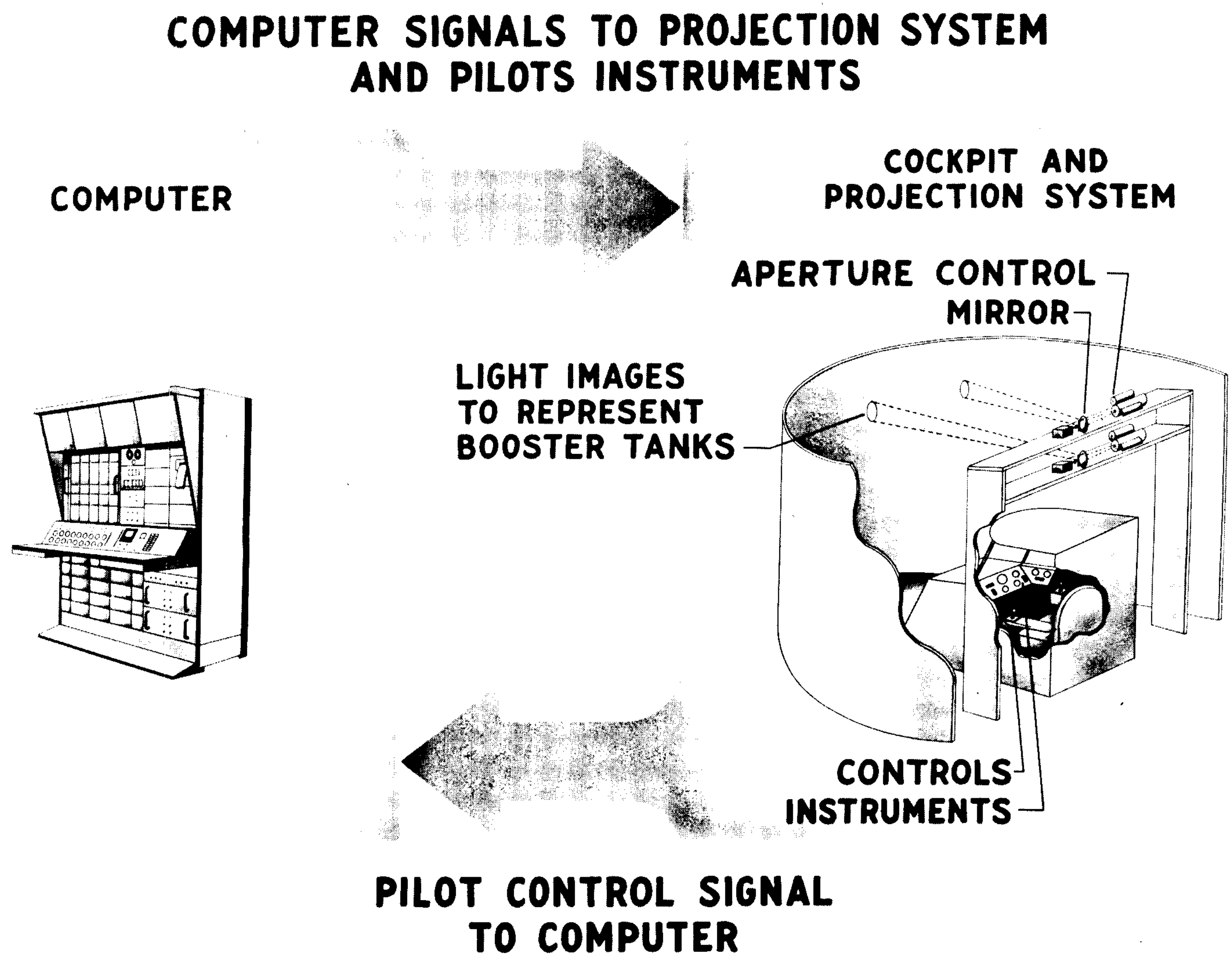

Figure 3.- Visual simulator for remote docking.

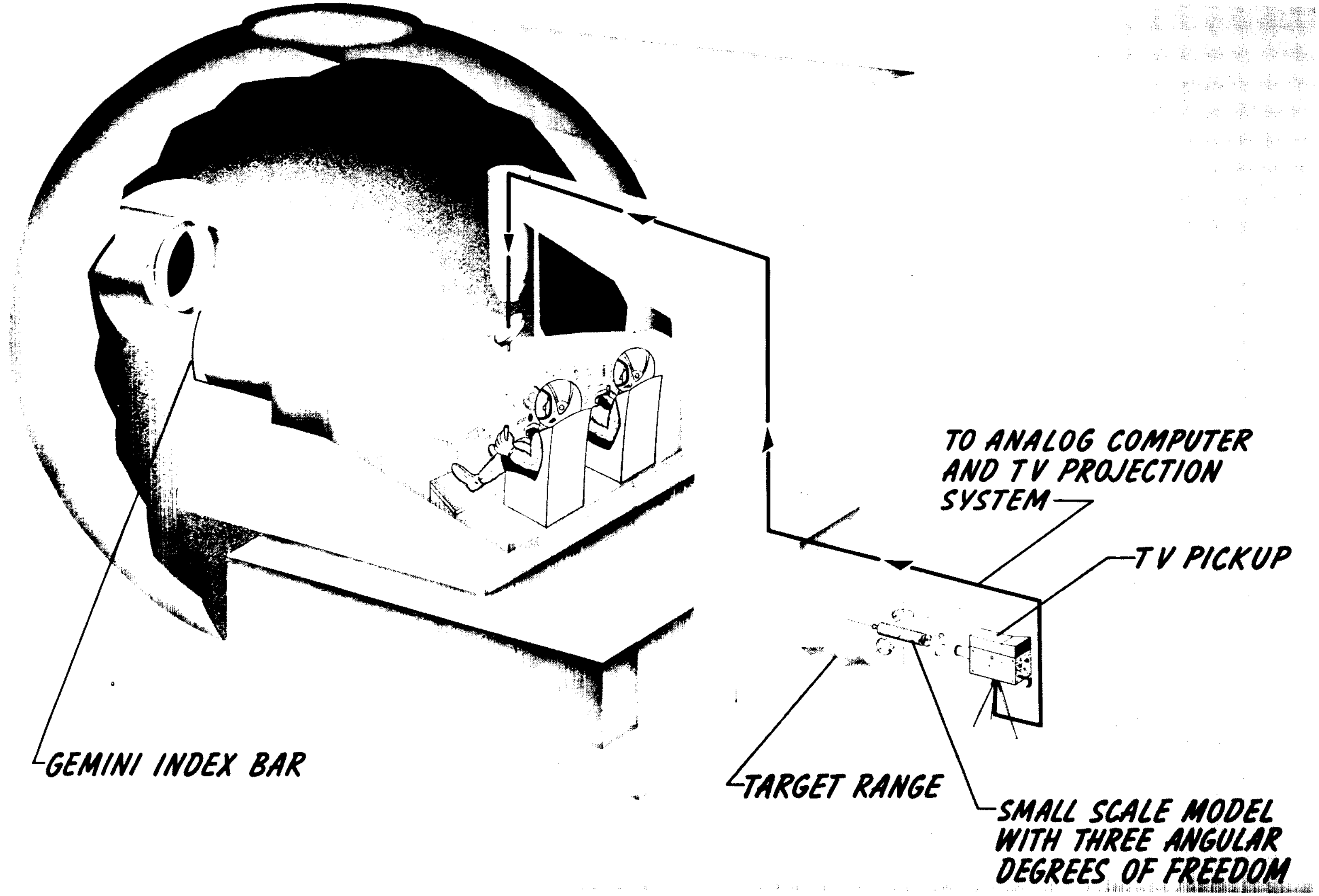

Figure 4.- Visual docking simulator.

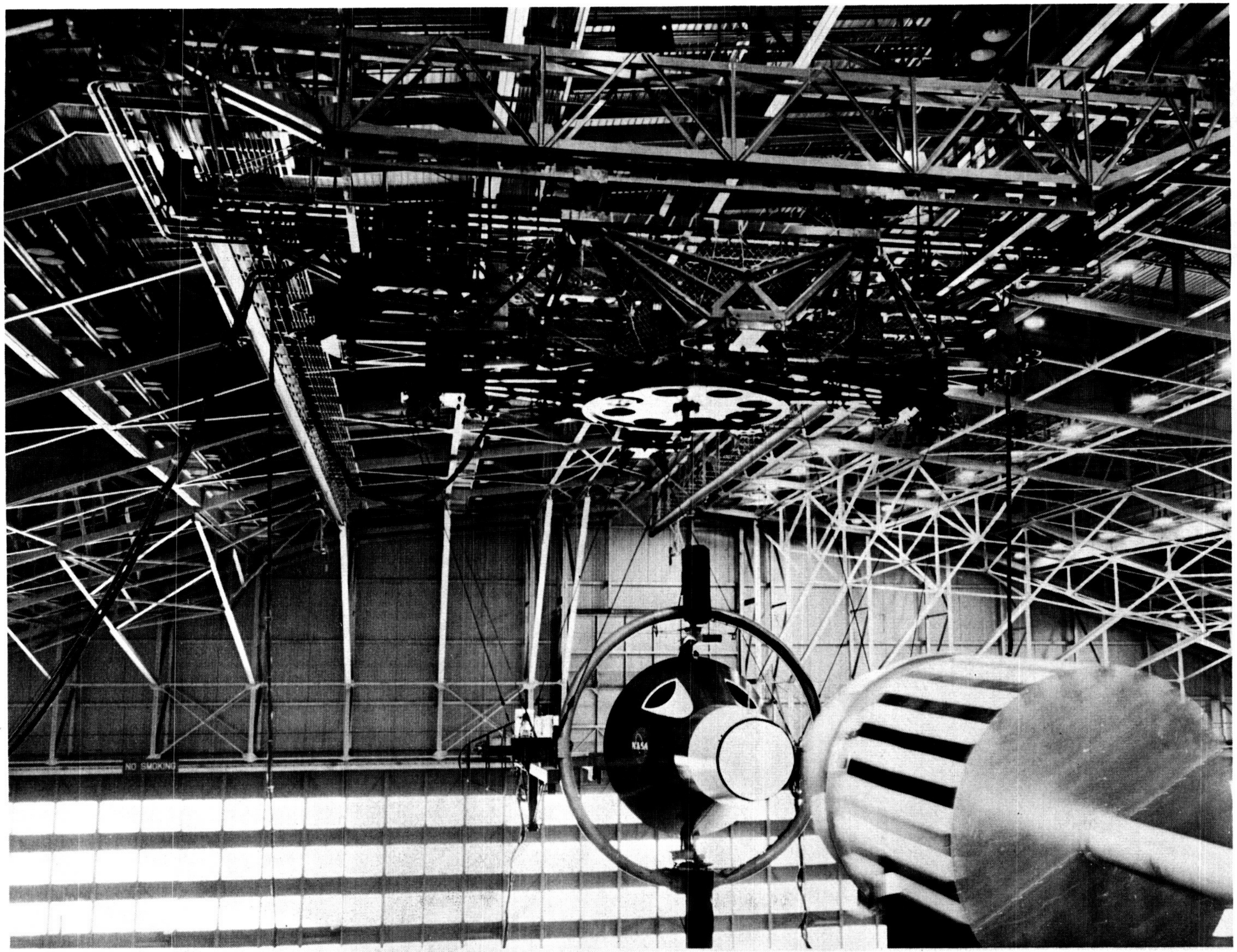

Figure 5.- Full-scale rendezvous docking simulator.

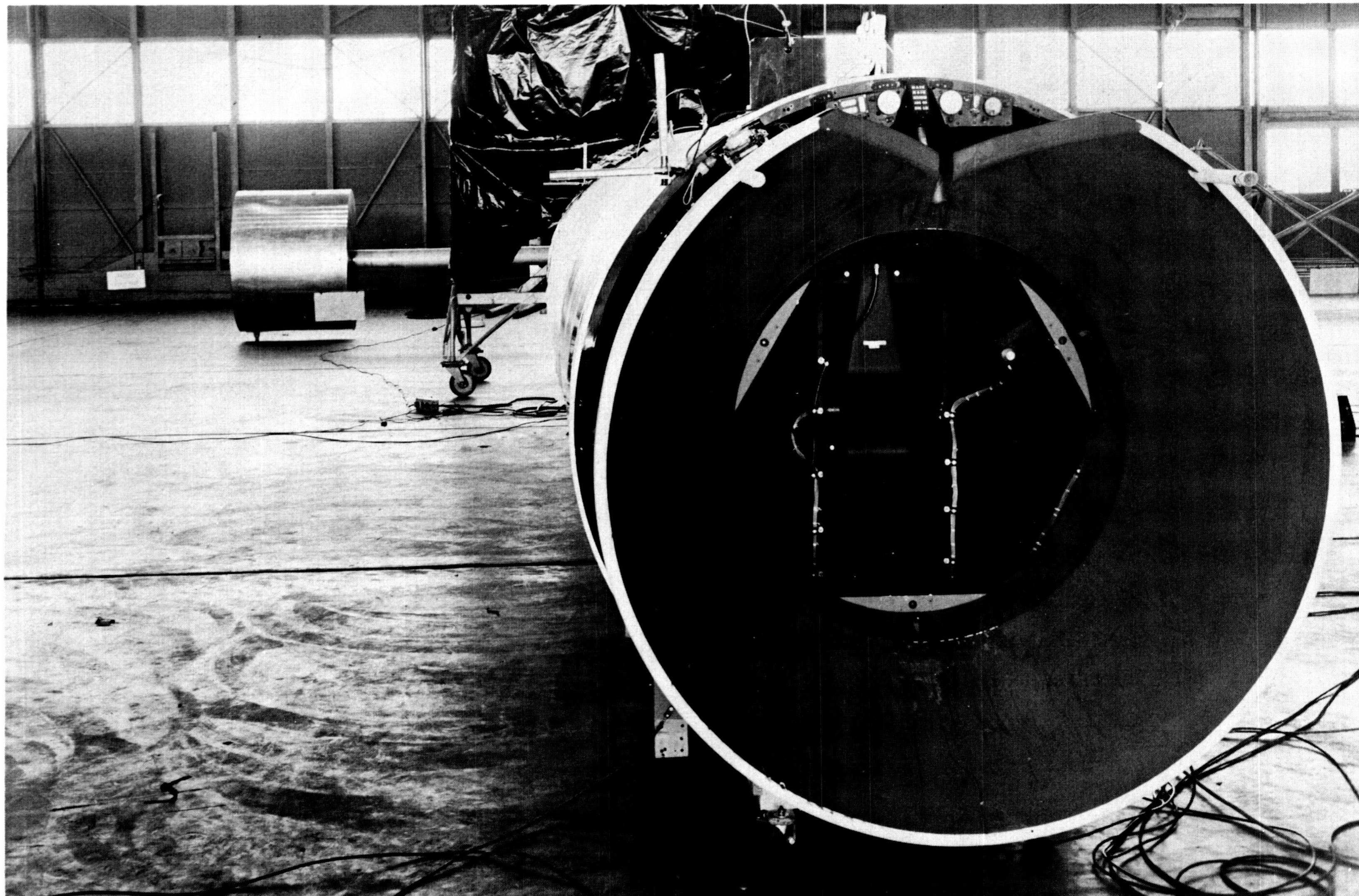

Figure 6.- Production target docking adaptor (TDA).

NASA-Langley, 1964