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SUMMARY

An investigation of the use of closed-circuit television (CCTV) as an instrument for pilot-controlled visual docking of two space vehicles was conducted on the Langley rendezvous docking simulator (RDS). The RDS is a full-scale dynamic facility which is used to study pilot-controlled docking of various types of space vehicles. The vehicles simulated in this study were the Gemini spacecraft and the Agena booster.

The first part of this two-part study was designed to compare the pilot's ability to remotely control a docking by using only information obtained from a television monitor with his ability to control the docking by direct vision from within the spacecraft. For the remote flights a closed-circuit television camera was mounted in the Gemini cockpit with the camera lens fixed at the pilot's cockpit eye position. Comparison of the results of the first part of the study with earlier Gemini docking studies shows that the error band (of terminal accuracies) of docking with the CCTV is very similar to that in actual visual docking.

In the second part of the study the camera was mounted in the Gemini nose with the lens center line along the longitudinal axis of the vehicle, so that the camera saw no part of the Gemini vehicle. An integral part of this camera location was a visual aid mounted on the target (the Agena booster). Three generalized vehicle-control systems were used in order to obtain more general results and to show the effects of the control system on the pilot's control of the active vehicle. Results of the second part of the study show that, with the assistance of the visual aid on the target, the pilot could commit to a docking with small error.

INTRODUCTION

In future manned space-vehicle operations, some instances will arise in which the astronaut must control vehicles he cannot see directly. In a situation such as this, the pilot would either be remote to the operation or merely unable to see directly the work he is doing. Such conditions may arise from considerations of vehicle design and crew safety. Hence a means must be provided to give the pilot a visual display of the problem or proper and sufficient instrumentation to replace the loss of direct visual observation.

One task for which direct vision is advantageous is the docking maneuver. The present Gemini vehicle designs provide the pilot with a direct view of the docking operation. Much work has been done in the study of Gemini docking problems with a direct view as indicated in references 1 and 2. However, little consideration has been given to providing the pilot with a visual scene of the problem when he is either unable to see directly or is remote to the active vehicle. If the Gemini or some other craft were used as a space tug for transporting supplies, possibly radioactive or dangerous, perhaps the pilot would have to be remotely located for his own safety and would not be able to see where he was depositing his supplies. If this were the case, then one means of giving the pilot a suitable view would be to mount a television camera on the load or on the spacecraft so that the docking interface could be seen.

The purpose of the present study is to investigate a means of supplying the pilot with adequate visual information for docking when he is remotely located. The means chosen is to locate a television camera on the simulated Gemini model and transmit the camera's view to the remote pilot.

A television monitor provided the pilot with a view of the operation as the camera saw it. Two locations were chosen for the camera. The first location was in the Gemini cockpit with the lens at the position where the pilot's eye would be. In this location the camera saw what the pilot would have seen had he occupied the cockpit. The results of this part of the study are compared with studies made earlier in which the same pilots flew from inside the Gemini cockpit. The second camera location was in the nose of the Gemini spacecraft. This second part of the study is a continuation of the investigation of the use of CCTV. However, no comparison of results is made with any other study or with the first part of this study. Since the target lacked sufficient visual information for this camera location, a visual aid was developed and is discussed herein.

SYMBOLS

The units used for the physical quantities defined in this paper are given both in U.S. Customary Units and in the International System of Units (SI) (ref. 3). Appendix A presents factors relating the systems as used in this paper.

Figure 1 presents the translation coordinates used herein.

x_t center-of-mass position in x direction of vehicle with respect to target, ft (m)

y_t center-of-mass position in y direction of vehicle with respect to target, ft (m)

z_t center-of-mass position in z direction of vehicle with respect to target, ft (m)

y_n lateral nose error of vehicle with respect to target, ft (m)

z_n vertical nose error of vehicle with respect to target, ft (m)

θ pitch error of vehicle with respect to target, deg

φ roll error of vehicle with respect to target, deg

ψ yaw error of vehicle with respect to target, deg

w_f weight of total fuel used, lb (kg)

t flight time, s

x,y,z inertial coordinates

A dot over a quantity represents the first derivative with respect to time.

APPARATUS

Simulator

The Langley rendezvous docking simulator (RDS), a full-scale dynamic six-degree-of-freedom facility used to study docking of various types of space vehicles, is shown in figure 2. (See ref. 4.) A full-size model of the Gemini spacecraft, which is the active vehicle in this study, is mounted in a hydraulically driven three-axis gimbal system which provides pitch, roll, and yaw attitudes. This gimbal system is then suspended in a horseshoe-shaped frame which is suspended by eight cables from an electrically driven overhead carriage-dolly arrangement which provides the three degrees of translational freedom. The attitude and translation systems respond to the pilot's control inputs through a programed analog computer. The pilot's control inputs cause voltage signals representing thrust to be transmitted to the computer where they are transformed in the computer from the body axis system to an inertial coordinate system.

Target

Figure 3 shows the model of the Agena booster used in this study. The model was a wooden cylindrical frame 25 feet (7.62 m) long covered with translucent paper. The docking adapter cone was of balsa wood and bakelite.

Television Equipment

The 800-line horizontal resolution, 675-scanning-line television unit used for this study consisted of two monitors, a control package, and a camera. One of the monitors and the control package are shown in figure 4. The camera can be seen in figures 5 and 6. A more detailed description of the specifications of the system is given in table I.

Prior to each set of runs, the control box and camera were adjusted to obtain a picture which was satisfactory to the pilot in quality, detail, and contrast. After the image conditions were manually selected, the control box was switched to an automatic mode. In this mode, the automatic light compensator maintained the same image conditions on the monitor regardless of the change within a design limit of the light incident on the target. For any large change in light intensity, the compensator stabilized the image quality under the new conditions. That is, the image did not wash out because of large changes in the light intensity incident on the target.

Pilot Compartment

The pilot was located in an inflatable planetarium (fig. 7) adjacent to the RDS, which is used primarily to simulate the darkness and void of space. The pilot sat before the television monitor in a chair, as shown in figure 4. Figure 8 shows the attitude controller which was used with his right hand, and figure 9 shows the translation controller which was operated by his left hand. By actuating these controllers with only the visual information supplied by the monitor, the pilot controlled the alinement and closure of the vehicles to docking.

TEST PROGRAM

Camera in Cockpit

The first part of the study was conducted with the camera in the left side of the cockpit of the Gemini model (fig. 5). The camera was positioned so that its lens occupied the same cockpit location as the pilot's eyes.

The purpose of this part of the study was to determine the feasibility of using CCTV by comparing remote runs made with the camera in the cockpit with runs using direct vision made by the same pilots in an earlier study. The data of these earlier runs when the pilots were in the cockpit were taken from references 1 and 2.

Camera in Nose

The second part of the study was conducted with the camera in the nose of the Gemini spacecraft (fig. 6). The nose plate of the spacecraft was removed and the camera positioned so that its lens looked along the longitudinal center line of the spacecraft, that is, there was no parallax due to the camera location.

This part of the study was conducted to investigate the effect of the pilot not being able to see the body of his own vehicle. With the camera in the end of the Gemini nose there was no part of the spacecraft in the picture as in the case where the camera was in the cockpit; thus, the spacecraft served as a camera mount only and not as any defined vehicle. To insure that this configuration was a generalization, the thrusting levels of the rockets were arbitrarily set at nominal levels of 0.4 fps^2 (0.122 m/s^2) in translation and 0.4 deg/s^2 in attitude; a generalized 50-percent attitude-translation cross coupling was used. Thus the coupling in attitude resulting from a translation command required half the available attitude-control power to overcome the acceleration. The same effect on translation occurred when attitude control was commanded.

Cross coupling occurs because the jets do not fire through the center of the vehicle mass. Hence a firing to cause translation up, down, left, or right created an attitude rate in pitch down, pitch up, yaw right, or yaw left, respectively. In this case, a 2-second firing of a jet to cause vertical rate also created a pitch rate which required 1 second of attitude firing in pitch to stop the attitude rate.

Target Visual Aids

The initial runs made with the camera in the nose of the Gemini spacecraft were attempted without any visual assistance other than that provided by the target. The task of docking was very difficult because of insufficient visual information of position relative to the active vehicle to the target. This difficulty was intensified close to the target where the camera saw only the inside of the docking adapter which was white. Hence the pilots had to aline approximately 15 feet (4.57 m) in front of the target with poor cues of position and hold this alinement by intuition to docking. It was decided that some type of visual aid was necessary to provide the camera with a view containing sufficient visual information throughout the approach so the pilot could dock with a small error. Although runs were initiated only 50 feet (15.24 m) from the target, the aid was designed to be effective as far as 150 feet (45.72 m) from the target.

It was decided that a double-angle truncated cone would solve the problems. A cross-sectional drawing of this cone is shown in figure 10. A cone was used for two reasons. (1) Since the camera was viewing the end of cylinder, the center of which it had to aline with, a cone whose maximum diameter was mounted flush with the end of the cylinder as shown in figure 11(a) was in keeping with the geometrical shape. The sameness of shape was not an overly important feature but does allow for easy culmination of all cues whether from the aid or the target. (2) With the cone a sense of depth was retrieved, more so than would have been with a cross on each end of a rod. Two angles were used because it was desired to employ the cone as a visual aid for the entire run. The large-angle part of the cone was found very suitable for gross alinement at large distances while the small-angle part was used for fine alinement just prior to docking. It was later decided that this smaller apex angle would have been near optimum had it been 20° to 30°. The inner part of this cone faced the approaching camera as shown in figure 11(b). This view was transmitted to the monitor and the information used in the following manner:

If an attitude rate existed, then the aid seemed to translate across the monitor screen. On the other hand, if a pure translational-rate error existed, the concentric circles became increasingly nonconcentric while the aid translated a small amount compared with translation due to attitude on the monitor screen. For example, if the camera were high relative to the aid, the circles seemed to "bunch" at the top of the aid while spreading at the bottom. Using these two types of visual information, the pilot could distinguish attitude and translational errors and control them to docking.

Control Modes

In both parts of the study translation control was the direct (acceleration) mode.

With the camera in the cockpit, acceleration-command attitude control was also used. Thus, all six degrees of freedom were controlled by the acceleration mode with no damping. Gemini thrust levels and coupling, as defined in reference 1, were used.

In the second part of the study with the camera in the nose, three attitude control modes were studied. The mode of translation control was always acceleration command. The first attitude mode was an acceleration-command mode with 4 deg/s^2 rotational on-off acceleration in each axis. The second attitude-control mode tested was the on-off acceleration command mode with a rate washout circuit. With the rate washout feature, attitude rates established were damped out upon release of the controller, through a computer feedback loop having a 2-second time constant. The third mode studied, an on-off velocity command, was somewhat different. The signal from the controller was seen by the computer as a velocity of 0.4 deg/s. This velocity was integrated to a position to which the computer would drive the spacecraft. Thus there was attitude motion only as long as the attitude controller was displaced.

RESULTS AND DISCUSSION

Since the objectives and the simulation techniques used in the two parts of this study were different, the results and conclusions for each part are examined separately.

Camera in Cockpit

The results obtained with the CCTV camera in the cockpit can be compared with the results of the study reported in reference 2. The present remote docking study using the closed-circuit-television system was conducted immediately after the study in reference 2 with the same pilots and the same simulator. Two pilots designated A and B were used for this part of the study.

A run was considered to be finished when the longitudinal separation of the nose of the spacecraft and cone of target was zero. At this end point, the conditions were interpreted as the lateral and vertical nose error with respect to the cone.

Figure 12(a) is a plot of the end conditions for pilot A. The squares represent the lateral and vertical capsule nose error at docking for the case of the camera in the cockpit (pilot remote using CCTV). The small circles represent the errors at docking when the pilot was in the cockpit (pilot using direct vision). Figure 12(b) is a plot of the same type of data for pilot B.

In both parts of figure 12 the large circles represent the error bands within which the different set of runs fell. Comparison of the results for both pilots shows that the error band identified by the circles is smaller for the case when the pilot controlled from the cockpit; however, for all runs the end conditions were well within the 1-foot (0.3048-m) error band prescribed for Gemini-Agena docking. The main reasons for the larger spread of data for the camera-in-the-cockpit runs was the loss of depth and aspect when viewing the TV monitor. When viewing the TV monitor, the pilot only saw a two-dimensional image. Also, if he moved his head he could not see a change in aspect of the target that he would see when in the cockpit. This latter cue is considered to be helpful in visual docking. The loss of depth and aspect affected pilot A mainly in detection of vertical error whereas pilot B was affected in both lateral and vertical error.

In figure 12, the center of the large circles identifies the bias in nose error relative to a perfect docking. It is interesting to note that for both the camera-in-the-cockpit and pilot-in-the-cockpit cases there was a left lateral bias in nose position. The reason for these characteristics can be explained by inspection of figure 13. Figure 13 is a two-dimensional drawing depicting the position of the vehicles just prior to docking and explains the left bias in the end conditions. The pilots sat approximately 14 inches (35.6 cm) to the left of the longitudinal center line and hence had a visual parallax when looking at the nose of the spacecraft and guiding to a docking. The pilots took two measures to alleviate the work load caused by this parallax. One was to aline the eye (or camera lens) in a gunsight fashion with the docking bar on the spacecraft nose and docking slot on the target. While holding this alinement, the pilot flew high and to the left relative to the target to use the aspect of the side of the target for vertical and lateral translation cues. The pilots remained left and high during the approach until just before docking and then attempted to translate right and down to eliminate the error. Because of cross coupling, a command to translate right caused the capsule to yaw left. Hence the nose was slightly to the left at docking.

The reason for this difference of results for the pilot in the cockpit and the camera in the cockpit can be seen by a further investigation of the technique of approaching high and to the left. When the camera was in the cockpit, the pilot saw only a two-dimensional image, that is, the dimension of depth was lost. Loss of aspect was realized when the pilot moved his head relative to the TV monitor and did not get a change of aspect of the target. As can be seen from figure 12, this loss of depth and aspect affected pilot A only in detection of vertical rates and position, causing his vertical error to be greater and in a more random distribution. Pilot B was affected in both lateral and vertical sensing.

During the pilot debriefing it was stated that more caution was exercised during a TV approach compared with flights made from within the cockpit, yet there was no fear of making an unsuccessful docking. To clarify this feeling of the pilots, plots were made of total fuel used against flight time for each run. (See fig. 14.) The results of remote (camera in cockpit) and direct-vision (pilot in cockpit) flights are superimposed.

Figure 14(a) shows that, for the direct vision flights, the pilot used a minimum amount of fuel for a run time of approximately 75 to 80 seconds. For a flight of shorter duration the fuel consumption increased because the closure rate was high, and the pilots "over-controlled" in their anticipation of docking and hence used more fuel. For flight times of greater durations than the nominal 80 seconds, the fuel consumption also increased because the pilot took more care as indicated by a slower closure rate and used more corrective inputs. This result indicated that for this task, based on fuel use, a flight time of 80 seconds was optimum and represented a closure rate of 0.625 fps (0.191 m/s). A look at the overall end conditions of hundreds of runs made by pilot A, however, showed that a 75-to-80-second flight time was not optimum. The investigation indicated that accuracy of docking and consistency of this accuracy began to occur at a flight duration of about 110 seconds, and an optimum flight was a trade-off between accuracy and fuel use. Now notice that, with the camera in the cockpit, the pilot's minimum flight time was approximately 110 seconds. This longer time is an indication that the pilot was using increased caution. That is, he realized the problems and the limitations of closure rate at which he could still dock accurately. Figure 14(a) shows that the TV (camera in cockpit) runs followed the same pattern as piloted runs beyond 110 seconds, and these results agree with the pilots' comments that they did not change their technique of approach and docking. Figure 14(b) shows the same results as figure 14(a), however, with a lower fuel-consumption level for the TV runs. Less fuel usage indicated the pilot had become better trained, that is, he used less fuel for the TV case because he had more experience and had become more proficient at docking in general.

The slopes of the two curves are about the same; hence, the change of fuel consumption for a change in flight time remains the same. This agreement plus the pilot's statement does strongly suggest that there was no change in technique or in workload other than the realization of limitations of approach rate and cues and working within these limitations.

Control-Mode Study With Camera in Nose

As stated earlier, the second part of the study with the camera located in the nose was not made for a comparison of data but simply to detect the effect of a two-dimensional picture with no own-body references. Table II is a chart of the average end conditions for runs made by pilots A and B for the three types of attitude command. Variables are y_t, z_t, lateral- and vertical-c.g. error; y_n, z_n, lateral and vertical nose error; θ, φ, and ψ, pitch, roll, and yaw, respectively. All variables are defined with respect to target position.

The results show that the final nose errors became smaller as the control mode in attitude became easier. Generally, acceleration command is considered the most difficult mode. Rate command and rate washout command are usually considered less difficult - the order of difficulty depends on pilot experience. Pilot A seemed to do better in rate-washout command, because it was a simplified version of the acceleration command with which he was highly trained and proficient. Pilot B, who was not as highly proficient, had the trend of becoming much more accurate in the mode usually considered the easiest case (rate command). For both pilots the improvement in pitch error, θ, from the acceleration to the rate and rate washout commands reflects the difficulty of detecting vertical alinement. Errors in roll, φ, and yaw, ψ, also improved steadily.

Table III is a chart of average values for the number of control inputs per run in each degree of freedom, flight time, translation jet fuel use, attitude fuel use, and total fuel use per run.

The flight time for both pilots showed very little change for the different control modes. So even if the mode was easier there was no attempt to establish a higher approach velocity. The reason for a slow approach was attributed to the accentuation of the motion on the monitor. This accentuation was produced because the camera was on the end of a lever arm (nose of spacecraft) with a center of rotation some 8 feet (2.44 m) aft.

The final point of interest is the fuel consumption. The total fuel consumption increased for both pilots as the control mode became easier. The reason for this is twofold. As the attitude control mode became easier to manage, less emphasis was placed on attitude control and more emphasis was placed on translation control. However, the translation thruster levels were higher and required more fuel for a given input than the attitude thrusters. Also, though the pilot made less use of attitude control, automatic jet firing was required for attitude stabilization and made the rate-command mode easier to fly but required just as much or more attitude fuel.

PILOT COMMENTS

It was important that the pilots who flew the system were given an opportunity to state their remarks and conclusions about the work they had done.

After each pilot had completed his data flights for a part of the study, he was debriefed.

The following are the statements, opinions, and ideas of these pilots for the cases just discussed.

Camera in Cockpit

Following the runs with the camera located in the cockpit, the first question gave the pilots an opportunity to state their opinion of the simulation: How feasible do you feel docking via TV is? The pilots' comments were

Pilot A: "I think docking with a TV picture of the task is very feasible. As a task, it is easily accomplished."

Pilot B: "I think docking with a TV picture of the task is quite feasible. Like anything else docking by visual information transmitted to you by TV is going to take a little practice to gain proficiency; however, it is quite feasible."

They were asked what percentage of runs they felt they could complete within the docking tolerances established for Gemini-Agena. One pilot felt that he could complete 100 percent of the runs, while the other estimated 85-percent success. The reasons given by the second pilot for this limitation of accuracy were: Picture quality, loss of aspect of target, loss of three-dimensional cues on the target, and the inability to detect range and range rate adequately. All the pilots suggested that for instrumentation they would like to have at least a range indicator in a 'heads-up' location.

The pilots were asked to discuss their ability to separate attitude and translation positions and rates; their comments were:

Pilot A: "I could distinguish attitude rates from translation rates; however, the translation rates were not as clearly defined as they were when I was actually in the cockpit. This is due primarily to the fact that you just can't see the target quite as well, because its image on the TV is not as well defined at its boundaries. As for positions, I could identify them about the same as in the actual pilot-in-the-cockpit case. But this was a small amount of trouble in clearly defining both rates and position."

Pilot B: "I believe the biggest problem was the poor quality of the picture, but in general the attitude and translation rates were fairly recognizable. However, it was hard to tell exactly when you were docked. Even if you moved in slowly, you couldn't tell exactly when you had your indexing bar within the V-slot unless you saw the target move when you hit it. This was because the TV picture was two dimensional, and you could not see the back of the target when close to the target. At first I was having difficulty getting my rates to zero. I couldn't see slight movements as I could when actually in the cockpit.

There was a little difficulty in separating attitude and translation - primarily in pitch and vertical translation. I think the problem would decrease with increased proficiency."

To improve their detection of rates and position, the pilots felt that the most necessary feature of the system was a good picture on the monitor. One pilot felt that visual aids on the target might be of significant value, while the other one did not feel visual aids were necessary.

The pilots were asked how much they felt the image quality on the raster could be degraded and still allow them to dock within tolerance. One comment was

Pilot B: "Well, I don't think it could have been much worse than what we had in some runs, because from the starting position (50 feet (15.24 m) from target) I couldn't even see the afterbody. Actually I was using only the face of the target with which to dock."

The pilots were then asked if they modified their technique of approach because of the difference between the television presentation and the out-the-window view they got in day runs they had made. Neither felt that he had to modify his techniques.

Their comments on the workload caused by the television compared with flying from within the spacecraft were

Pilot A: "I think the workload is about the same. I believe you lose depth perception and that's it. Other than that, it's not different."

Pilot B: "The workload in flying the picture seemed to be a little greater than flying in the spacecraft. I think this was primarily due to the fact that I had no seat-of-the-pants feel. I had to rely strictly on what I saw; therefore, if I had a poor picture quality my rates tended to get higher before I detected them."

Camera in Nose

After the flights with the camera in the nose, the pilots were asked which control mode they preferred. Pilot B stated: "I preferred the rate-command mode. I didn't have to worry about my attitude movements after I got them centered because they remained fixed. Then, all I had to do was fly the translation mode."

Pilot B's statement about the effect of the visual aid on control technique was: "My basic technique was unchanged. In the direct mode I was using more attitude control. That's because I was more or less trying to get my translation zeroed and then keep my nose squared away in the rings with my attitude contact. This is pretty difficult."

When asked about proficiency development, pilot A stated, "I think docking with TV camera in the nose is quite feasible. I can develop a proficiency of skill in which I can accomplish 100 percent docking. My proficiency would stay high longest in the rate-command mode."

Comments on the role played by the visual aid were:

Pilot A: "The aid to attitude control provided by the cone is real hard to explain because it is more or less a feeling - a sense - you develop from experience."

Pilot B: "The truncated cone as a visual aid is a great help, primarily in translation . . . . I think you could achieve accuracy within a 2° error band using the aid, but I feel it would be pretty tough."

Recommendations of possible changes in the visual-aid design were:

Pilot B: "As for additional lines, different cone angles, or different band widths, it's pretty nebulous. It would have been better if the outer cone could have been longer. The inner cone used for final docking was about the right size, perhaps a smaller apex angle could be used."

The question of what was the main problem in the overall simulation brought forth this answer

Pilot A: "I think the main problem in this simulation, as in the rest of our work, was being able to make tiny corrections at the last minute. The closer you get to the target the more those small residual rates show up."

Pilot B's opinion of docking capability with the camera in the nose was "Excellent."

CONCLUSIONS

The two-part study of the feasibility of using closed-circuit TV (CCTV) for remote control of space docking has been made.

With the television camera in the gemini cockpit, the following conclusions were made:

(1) Closed-circuit television (CCTV) is feasible as a back-up mode, but it is not desirable as a primary means of viewing if direct viewing could be used.

(2) There is little degradation in lateral and vertical accuracy at docking after the pilot is sufficiently trained. Occurrence of degradation is due to the loss of aspect and three-dimensional cues.

(3) There is a degradation of ability of the pilot to estimate range and range rate using CCTV. A 'heads-up' range meter is desirable.

(4) The pilots' techniques of approach and docking with CCTV were not changed from those of direct viewing.

With the television camera in the nose, the following conclusions were made:

(1) Some type of visual aid on the target vehicle would be required.

(2) With the truncated cone aid, pilot proficiency, and realistic control characteristics, a Gemini-Agena docking band of $\pm 2^{\circ}$ may be possible.

(3) The acceleration mode was found to be acceptable and used the least fuel of the three types of attitude control modes studied.

(4) The rate-command mode was easiest to control; however, the required automatic stabilization caused this mode to use more fuel than the other two modes.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., June 17, 1965.

APPENDIX A

Factors required for converting the U.S. Customary Units used herein to the International System of Units (SI) are given in the following table:

Physical quantity	U.S. Customary Unit	Conversion factor (*)	SI Unit
Length	in.	0.0254	meters, m
	ft	.3048	meters, m
Mass	lb	.454	kilograms, kg
Acceleration	ft/s^2	.3048	$meters/second^2$, m/s^2
Frequency	cps	1	Hertz, Hz
Velocity	ft/s	.3048	meters/second, m/s

*Multiply value given in U.S. Customary Unit by conversion factor to obtain equivalent value in SI Unit.

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TABLE I.- SPECIFICATIONS OF CCTV SYSTEM*

Input:	
Voltage, V	100 to 130
Current	ac
Frequency, cps or Hz	50 to 60
Power, W	185
Output impedance, ohms	75
Horizontal resolution, lines	800 or more
Signal-to-noise ratio, dB	40 or better
Scanning lines	675
Interlace ratio	2 to 1
Field rate, cps or Hz	60
Automatic light compensation ratio	6000 to 1
System bandwidth, mc	12
Tolerable ambient noise level, dB	up to 160
Camera:	
Dimensions, in. (cm)	4.5 × 10 × 6.56 (11.43 × 25.4 × 16.66)
Weight, lb (kg)	9(4.08)
Control package:	
Dimensions, in. (cm)	17.37 × 5 × 19.62 (44.12 × 12.70 × 49.83)
Weight, lb (kg)	4(1.81)

*As given by manufacturer.

TABLE II.- AVERAGE OF END CONDITIONS FOR RUNS WITH CAMERA IN NOSE

Command mode	Error in -										
	y_t		z_t		y_n		z_n		θ, deg	φ, deg	ψ, deg
	ft	m	ft	m	ft	m	ft	m			
Pilot A											
Acceleration	0.45	0.137	0.56	0.171	0.48	0.146	0.21	0.064	3.35	1.77	2.02
Rate washout	.25	.076	.47	.143	.21	.064	.20	.061	2.87	.37	.82
Rate	.44	.134	.75	.229	.23	.070	.27	.082	3.09	.51	1.23
Pilot B											
Acceleration	1.12	0.341	0.95	0.289	0.46	0.140	0.26	0.079	4.98	2.00	2.47
Rate washout	.49	.149	1.00	.305	.22	.067	.50	.152	4.69	.33	1.56
Rate	.18	.056	.45	.137	.08	.024	.19	.058	2.25	.39	.72

TABLE III.- AVERAGES OF INPUTS, FUEL, AND TIME FOR FLIGHTS MADE WITH CAMERA IN NOSE

Control mode	Average inputs per run for:						Total average inputs per run	Average flight time, s	Average translation fuel per run		Average attitude fuel per run		Average total fuel per run	
	x	y	z	θ	φ	ψ			lb	kg	lb	kg	lb	kg
Pilot A														
Acceleration	6.86	6.17	4.13	14.88	16.75	24.38	73.17	185.49	0.62	0.28	1.03	0.47	1.62	0.74
Rate washout	8.88	19.63	18.38	15.25	7.00	16.13	82.27	208.71	1.84	.84	.91	.41	2.72	1.23
Rate	8.01	33.00	24.00	13.50	4.38	16.13	99.02	202.29	3.30	1.49	1.61	.73	4.92	2.23
Pilot B														
Acceleration	2.14	11.13	8.25	13.83	14.83	25.17	75.35	216.42	1.54	0.69	0.59	0.268	2.13	0.967
Rate washout	3.00	19.70	16.30	9.80	6.10	10.90	65.80	209.27	3.12	1.42	.92	.418	4.40	1.99
Rate	2.63	19.75	17.75	13.95	4.75	10.25	69.08	215.90	4.85	2.20	1.97	.894	6.82	3.09

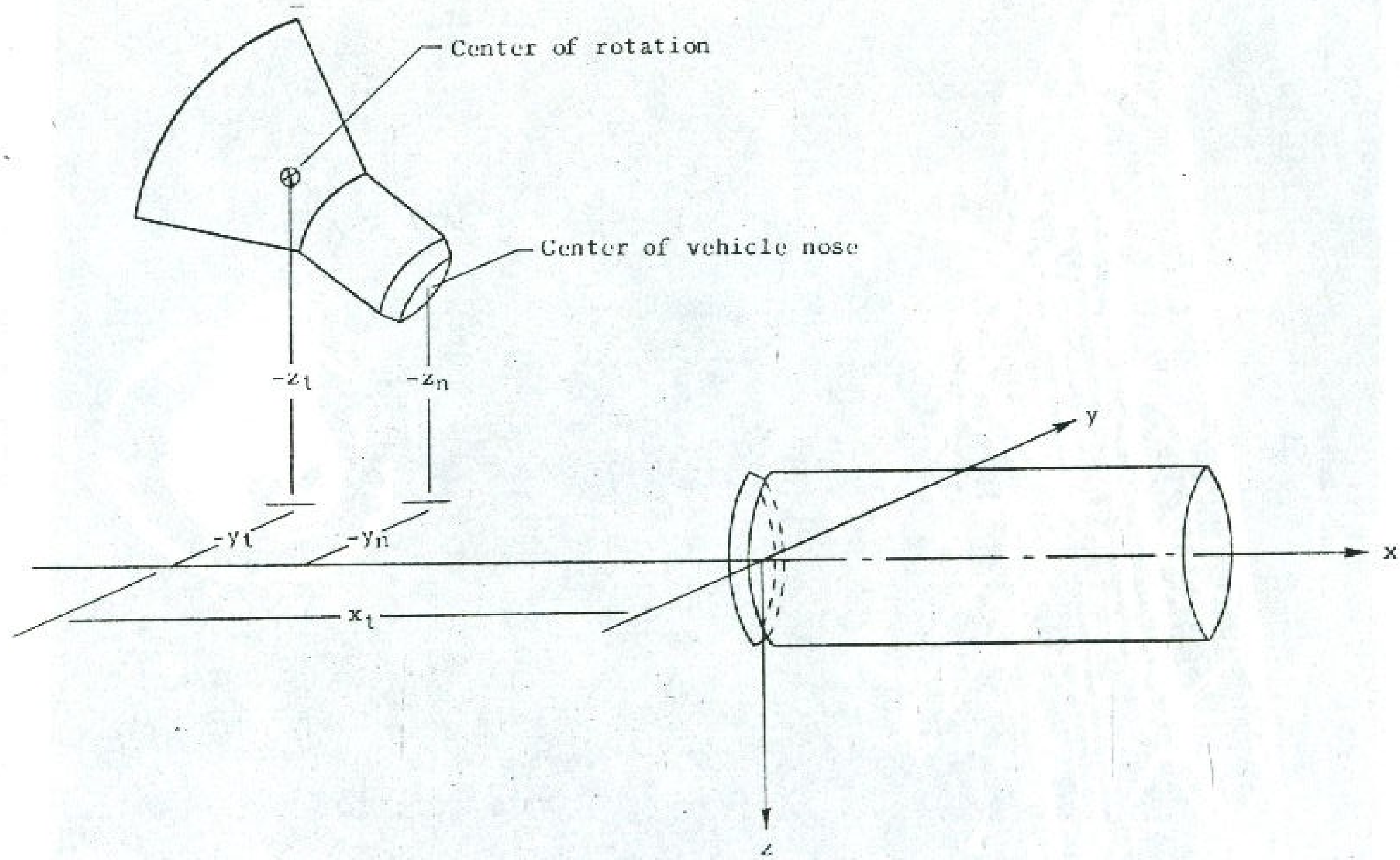


Figure 1.- Translation coordinates used in CCTV study.

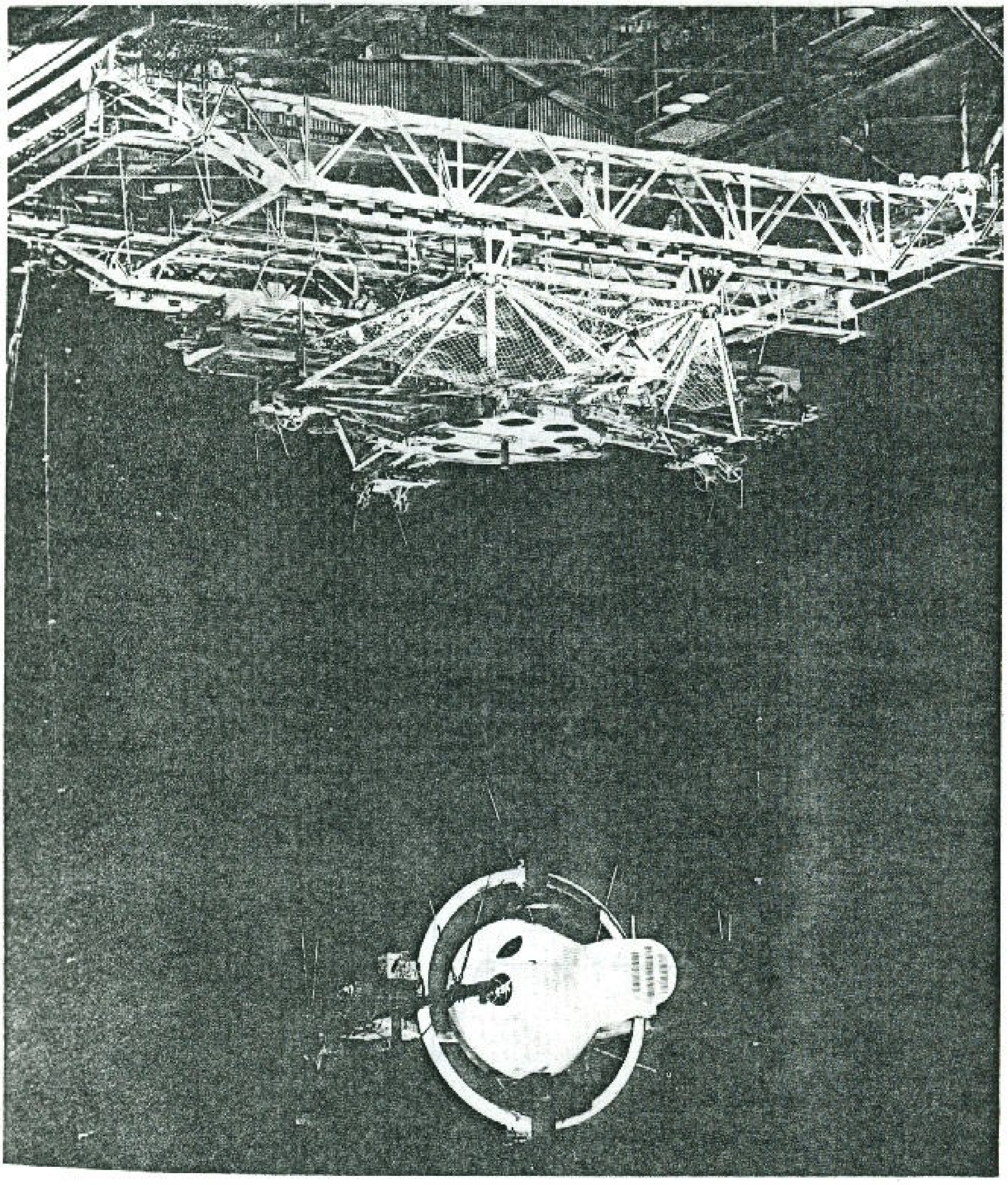
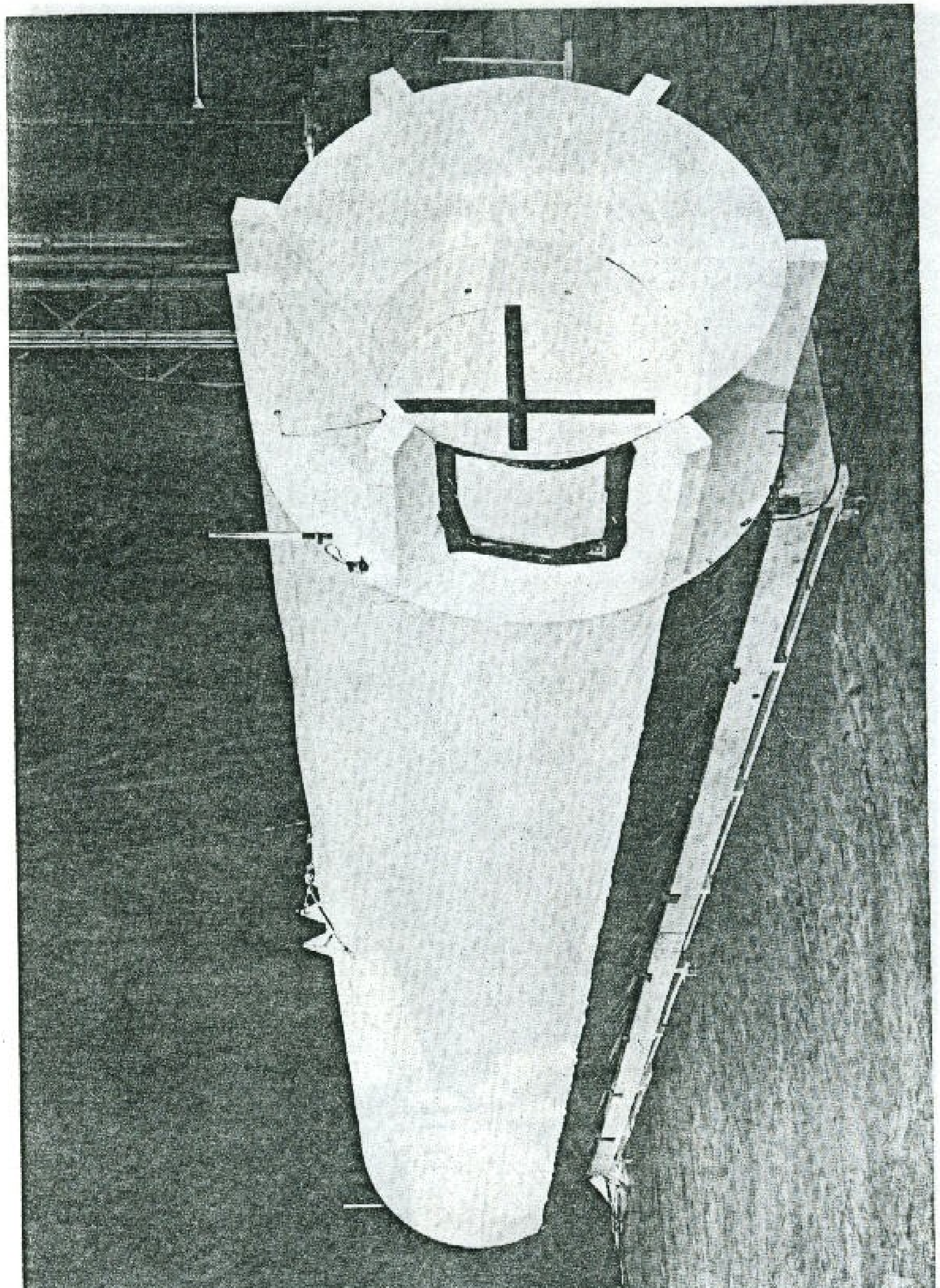


Figure 2.- Langley rendezvous docking simulator (Gemini configuration). L-64-4307



L-64-708

Figure 3.- Wooden mockup of Agena target.

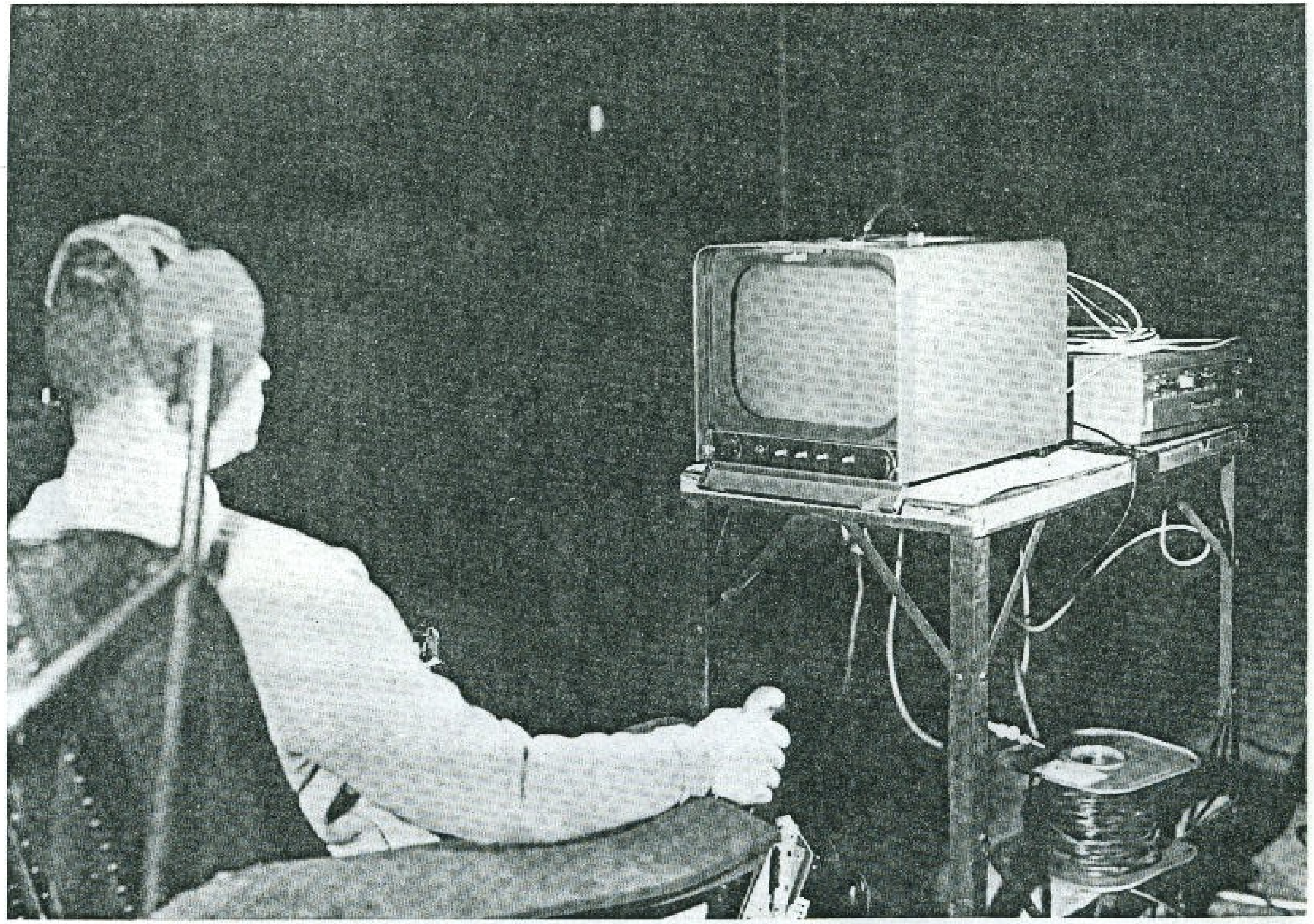


Figure 4.- Pilot position during docking simulation. L-63-10153

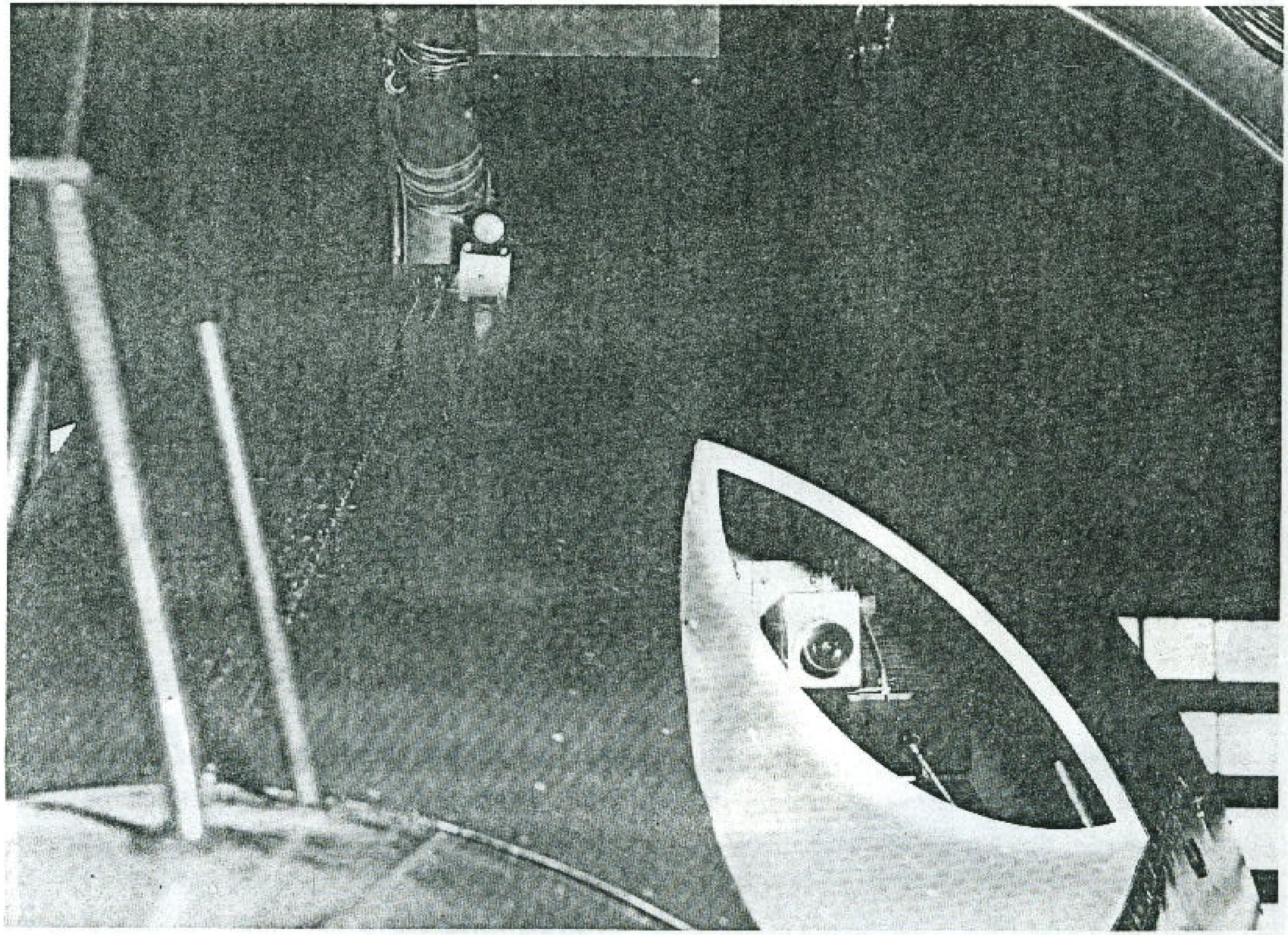


Figure 5.- CCTV camera in left side of Gemini model cockpit. L-63-10145

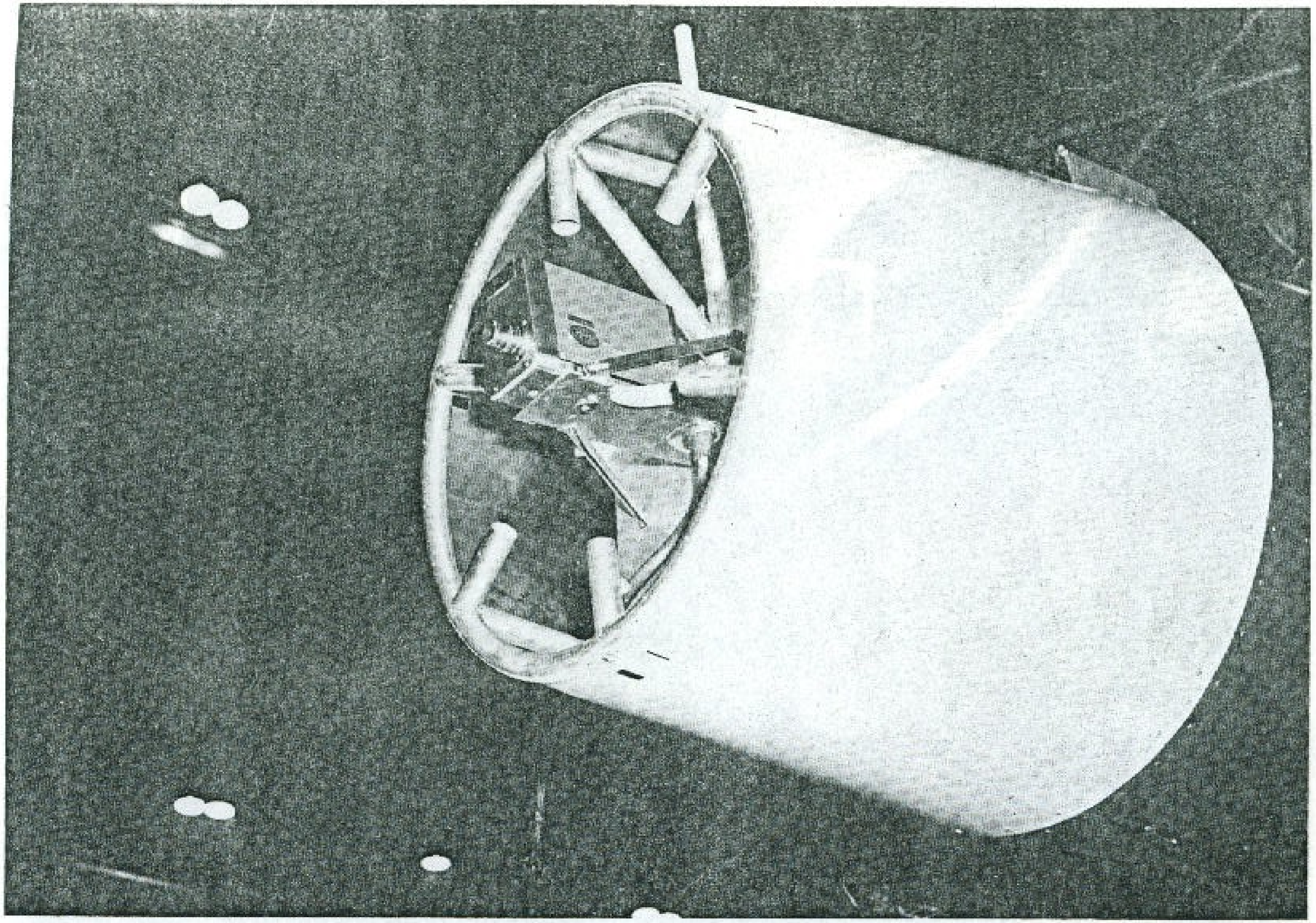
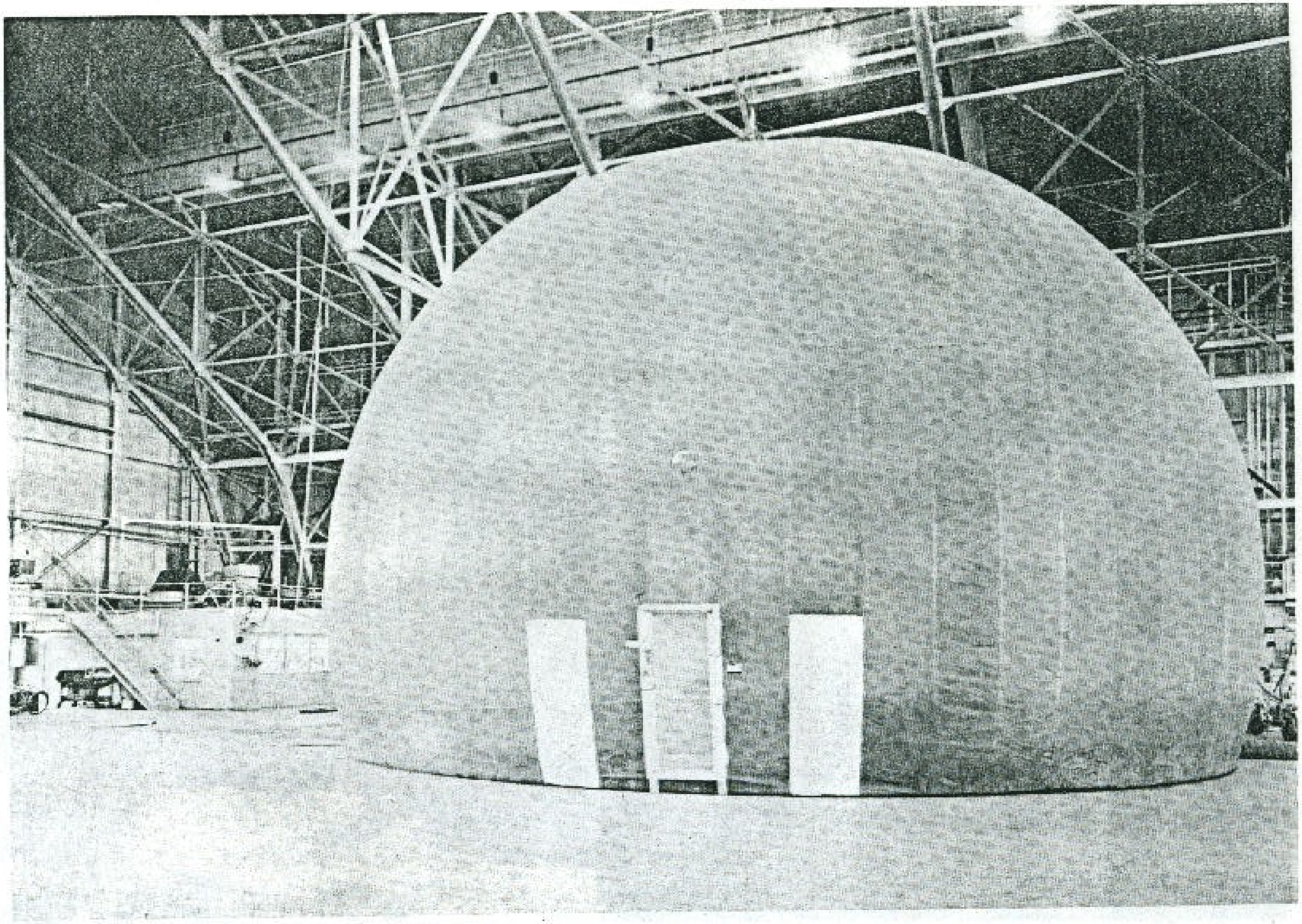
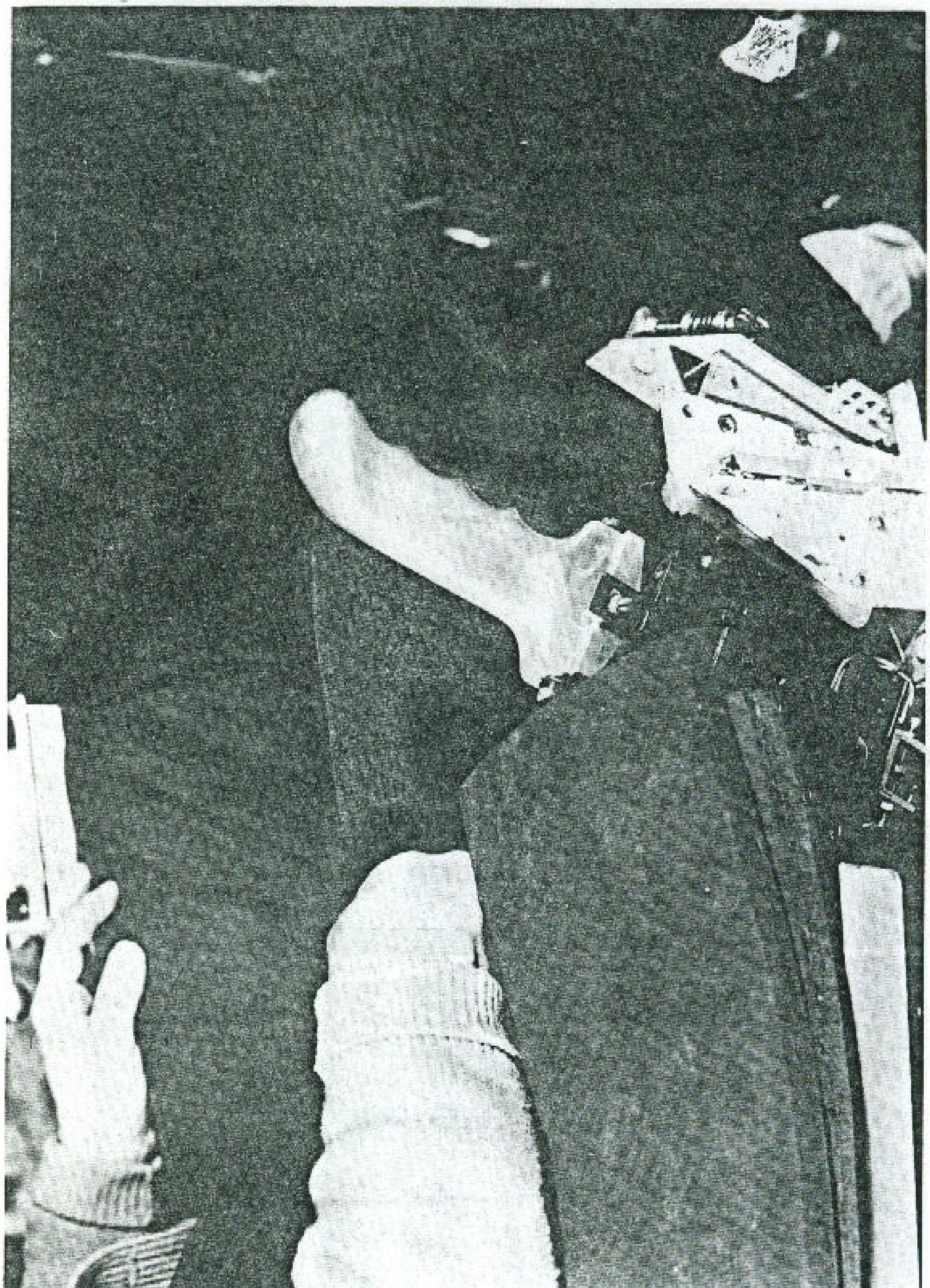


Figure 6.- CCTV camera in Gemini model nose. L-63-10147



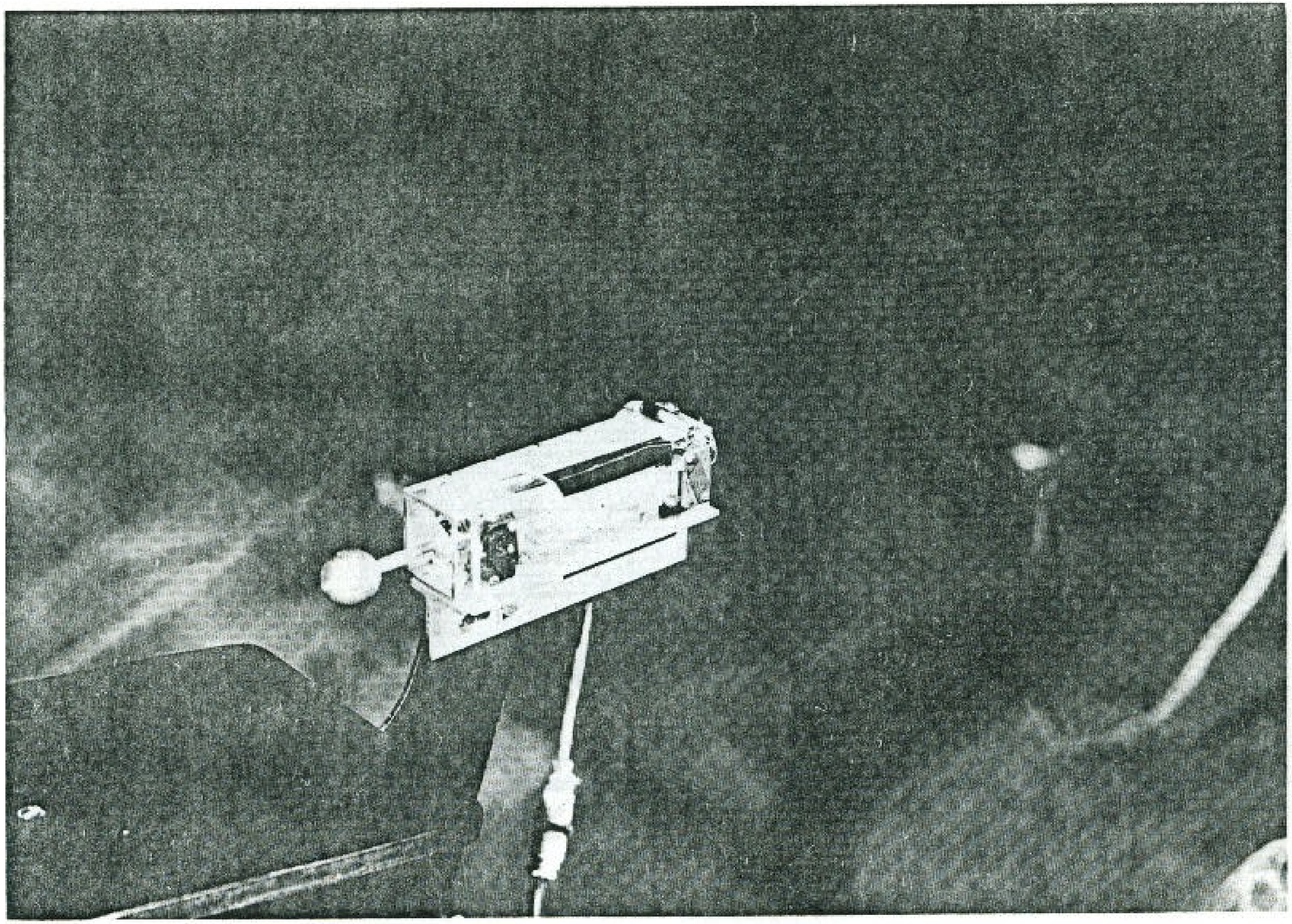
L-61-3399

Figure 7.- Inflatable planetarium.



L-63-10149

Figure 8.- Attitude controller.



L-63-10151

Figure 9.- Translation controller.

Symbol	Value, inches
a	.75
b	1.00
c	.50
d	14.25
e	.75
f	.25
g	2.00
h	8.50
k	3.90
l	13.25
m	5.30
n	4.70

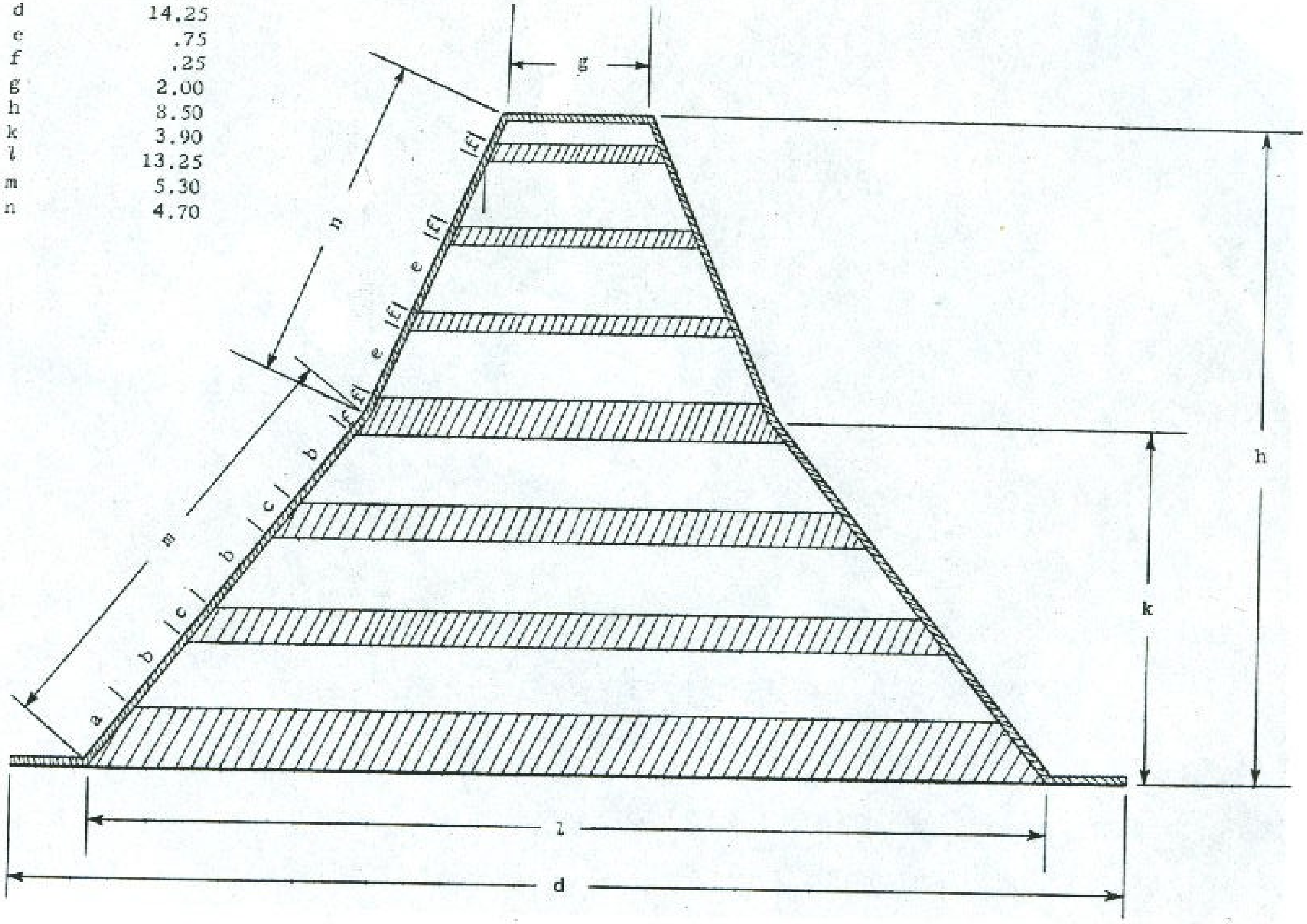
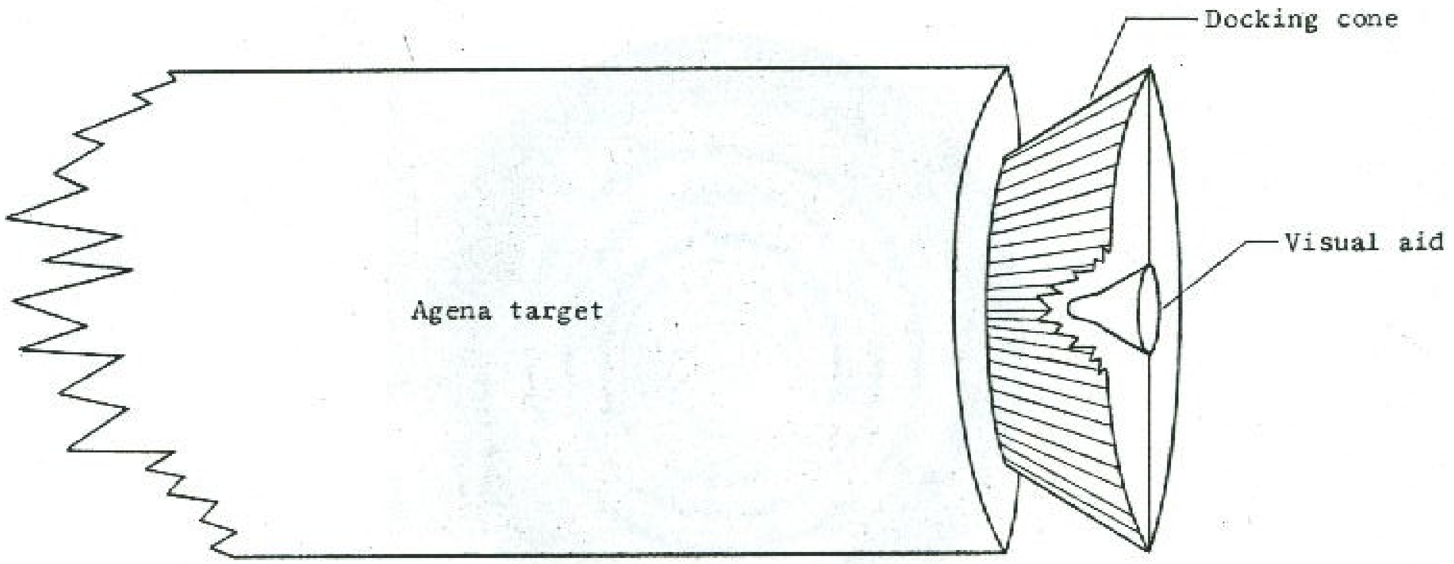
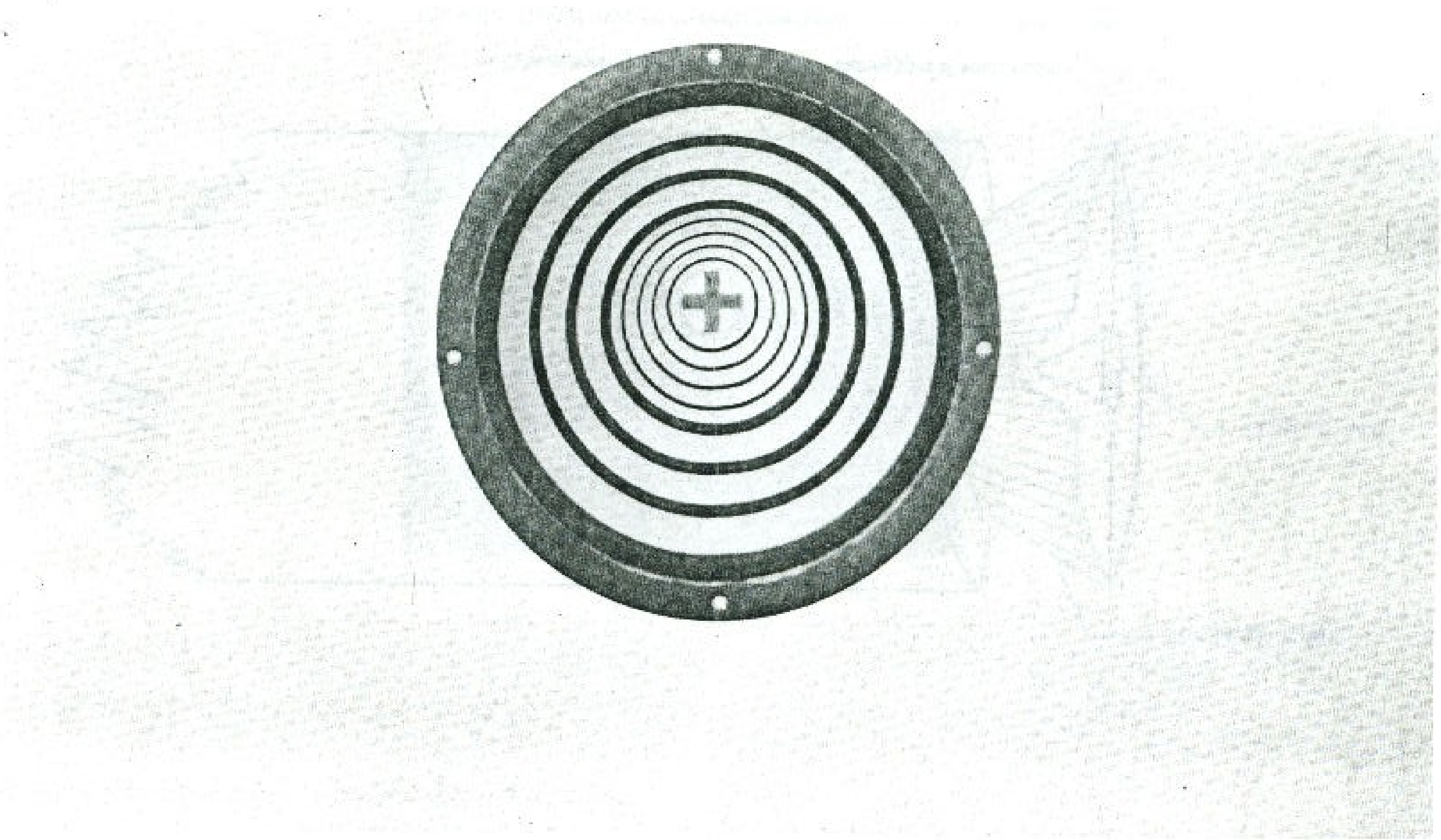


Figure 10.- Cross-sectional drawing of visual aid.



(a) Cutaway drawing of visual aid mounted in docking cone of Agena model.

Figure 11.- Views of visual aid (truncated cone) used for docking with TV camera in nose.



L-63-10152

(b) View of visual aid as seen by CCTV camera.

Figure 11.- Concluded.

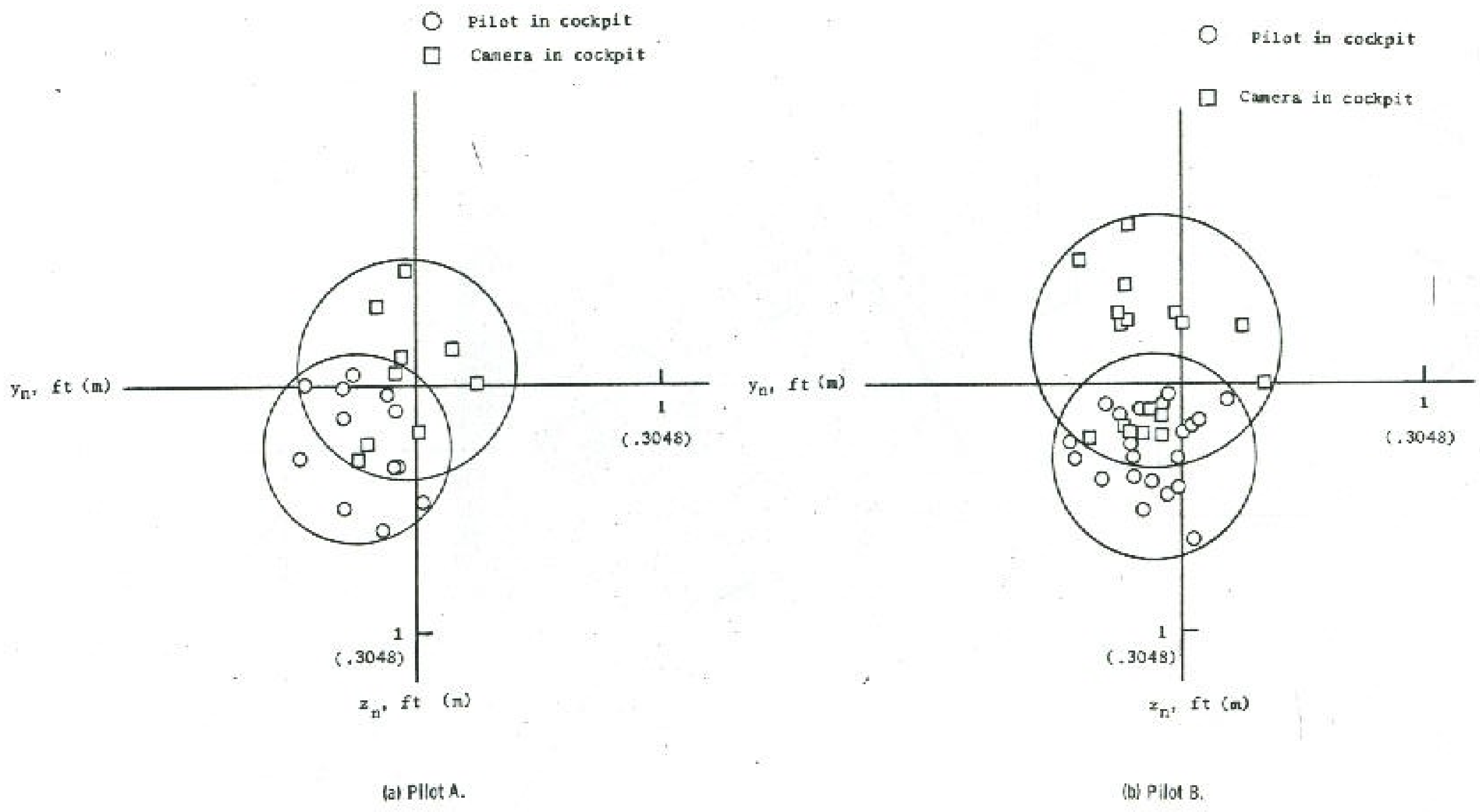


Figure 12.- Lateral and vertical error of center of Gemini nose with respect to Agena center line.

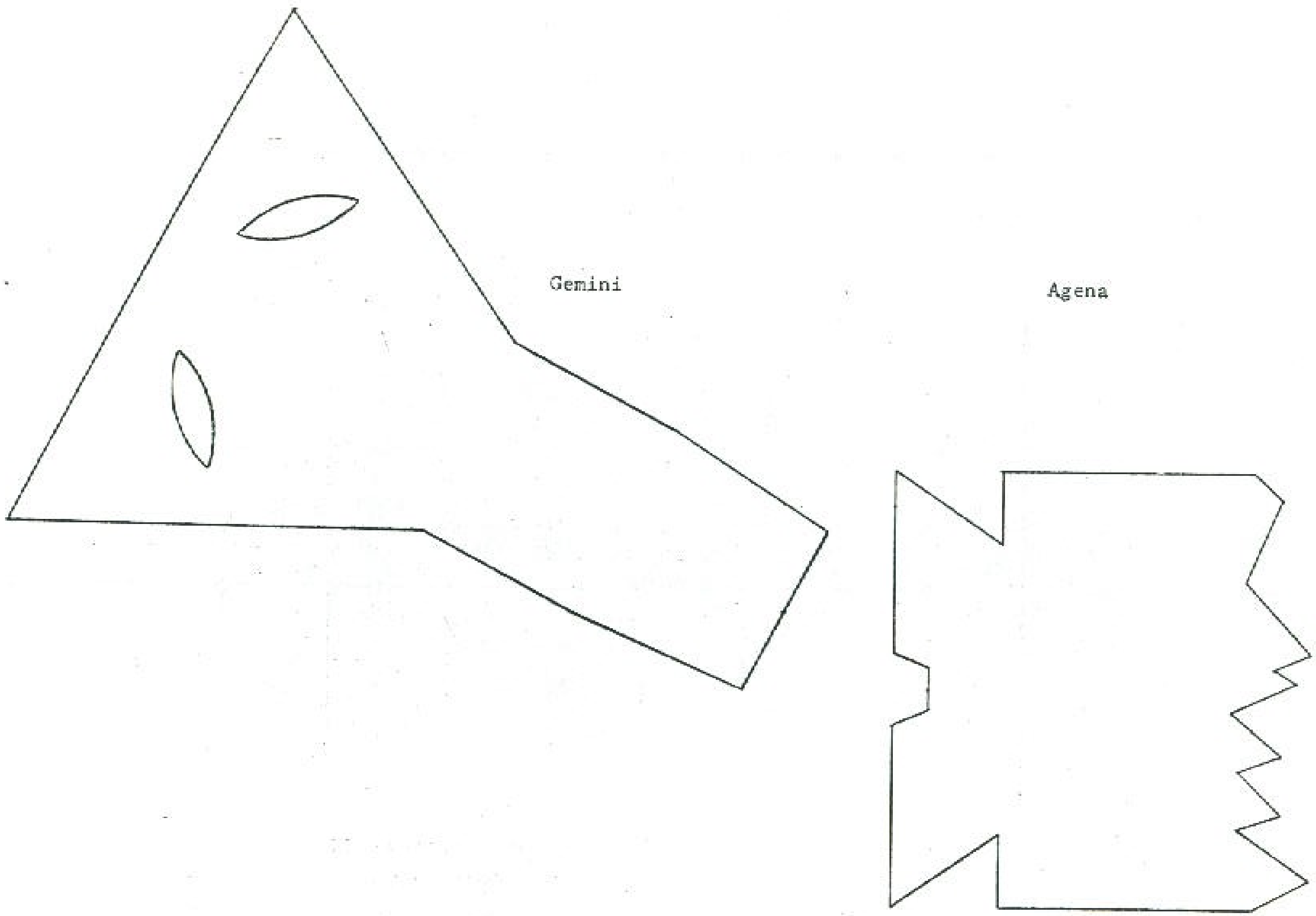
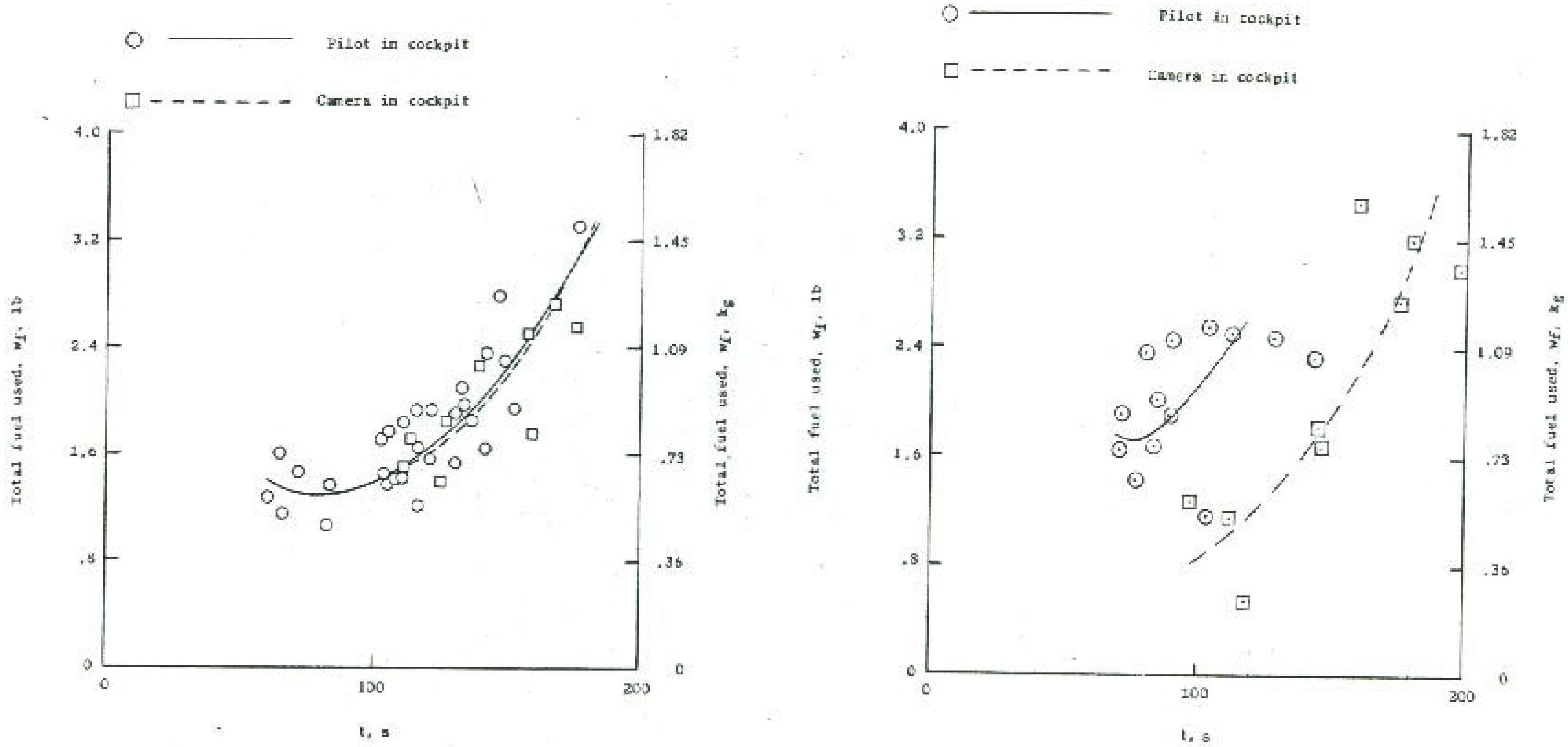


Figure 13.- Drawing of vehicles prior to docking.



(a) Pilot A.

(b) Pilot B.

Figure 14.- End-condition plots of total fuel used (pounds (kg)) plotted against flight time (seconds) for pilot in cockpit and camera in cockpit.