DISCUSSION OF EXISTING AND PLANNED SIMULATORS FOR SPACE RESEARCH

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SUMMARY

Man is an essential element in many of our space programs. In exploring the unknown only man can observe the unpredictable or react intelligently to the unexpected. Not only do we need man in space as an explorer and observer but we also need his capabilities in the management and control of our missions in order to improve their reliability and chances of success. To take full advantage of man's unique attributes we must study his capabilities, define them, and then using this information design our space systems so that he becomes an integral part of the mission. These objectives are accomplished through the use of manned flight simulators.

This paper discusses a variety of manned flight simulations that are particularly applicable to space research.. Most of the simulators described are in operation, but are relatively new. Some of the simulators are still under construction or in the planning stage. A few of the simulators are nonexistent

- that is, although the research problems have been defined no satisfactory methods for adequately simulating the problems have been found. The facilities described have been selected either because they present new and novel methods for simulating some of the peculiar aspects of the space environment or because they contain unique construction or operational features that may have application to other simulation facilities.

BASIC SIMULATOR COMPONENTS

Manned flight simulators are designed to study the human problems of how to manage and control our aircraft or space vehicles. In these facilities we try to simulate realistically those features of the environment which affect man's senses. These sensory inputs - what a pilot sees, feels, or hears - are used in flight simulators as sources of information by the pilot and govern his decisions and actions. Other inputs - environmental stresses - which normally have little information content and therefore do not have an immediate impact on pilot performance can, under certain circumstances, have an important effect and must then be included in a meaningful simulation. For this reason, some flight simulators must include these stresses and examples of these will be presented. On the other hand, manned simulators which are primarily concerned with the physiological effects of these stressful inputs are not the main subject of this paper.

The interrelationships of the various elements which may be required in a flight simulator are shown in figure 1, prepared by Mr. John Dusterberry of the NASA Ames Research Center. As this figure shows, the main objective of a flight simulator, regardless of what elements are included in or omitted from the main "box", is to study pilot performance in the accomplishment of any given task. To accomplish this task the pilot must operate his vehicle through his control system. The pilot cannot, however, operate blindly. He needs information in order to make his decisions and to observe the consequences of his actions. The pilot may obtain this information through his instruments, from his view of the outside world, or from motion cues. Finally, as shown, the pilot's "basic" capability or efficiency may be changed, either abruptly or gradually, as a result of the effects upon him of environmental stresses.

These are the basic components, or physical characteristics - present in varying degree - in all flight simulators. How these components are mixed and used determines the success or failure of simulation research.

THE ART OF FLIGHT SIMULATION

Research simulation is much more an engineering art than it is a science. An important ingredient for successful research simulation is timeliness. This is achieved primarily through foresight in anticipating and then defining problem areas, inventiveness and ingenuity in the rapid development of new simulation techniques, and in the efficient conduct of the research program. The value of the results is determined in part by the proper choice of the simulation hardware which is used, but mainly by the proper qualification of the conclusions which are obtained. These conclusions to be valid and worthwhile must combine both quantitative results and, of greater importance, qualitative results in the form of pilot opinion. In addition the conclusions often reflect the inputs from other disciplines such as from psychologists, physiologists, control systems engineers, etc. Because of the importance of these qualitative aspects, much of the value of simulation research is determined by experience. This experience must not only be individual in nature but must be experience of the group because of the interdisciplinary aspects of simulation work. This group experience is evident by close cooperation and coordination and by a clear understanding by all personnel of the problems involved in the research work.

In many respects successful research simulation is analogous to successful production of a Broadway play or a Hollywood movie. Referring back to figure 1 we can visualize the flight simulator as being analogous to the theater itself and the research personnel to the production company. It is the task of the production company to translate the author's (research scientist's) story (task) into a performance which the public or program office will buy. It is the responsibility of the director (project engineer) to mold all of the elements in his production to achieve the maximum result. He will call upon his set designers to provide the visual displays. He will ask his special effects men to create unusual effects such as simulated lunar gravity or weightlessness. He will use script writers to prepare his research and computer programs and he will employ prop men and technicians to provide the other facilities necessary. He will combine these facilities in varying degree depending upon the specific story he is directing. He will use a capable crew and a competent supporting cast headed by an experienced and talented "star." During rehearsals both the director and the "star" will be their own severest critics. They will continuously assess and improve the performance to try to get the most out of what they have available.

I do not want to continue this analogy much further except to say that experienced direction and a talented cast can produce an excellent performance with limited facilities. On the other hand, the best story and the best facilities cannot produce a good performance under poor direction or inexperienced acting. One common mistake made in simulation research is to use engineers with some flight experience as test subjects rather than to use experienced experimental research test pilots. It is not sufficient to simply perform in the simulation. It is necessary to bring experience and training to bear so that the performance can be interpreted and valid conclusions can be reached which properly take into account the limitations that are always present in any simulation equipment.

Just as the theater has developed a course of action in producing plays, research simulation has also evolved an efficient procedure which is illustrated in figure 2. This figure diagrams the research simulation process only at the task level. It should be realized that this same process may be carried back to the mission phase level and, in some instances, even back to the entire mission level. The process starts at the upper left with the selection of a research task or problem. The problem is examined and in this process may be broken down into subtasks, as shown. After each subtask has been defined, a choice of the most appropriate simulation facilities available is made. In some instances it is necessary to study a problem with more than one simulator. After the simulator has been selected the research program is conducted and both quantitative and qualitative results are obtained. These results are weighed and combined to form preliminary conclusions. These preliminary conclusions, in general, require that adjustments or changes be made to the basic simulation hardware or to the research program or even to the task definition. When this cycle has been repeated sufficiently so that everyone is satisfied with the conclusions, these are issued as research results. Sometimes, as shown, these conclusions combine the results of separate simulations which may have been necessary. These research results are used as inputs to the system design. Often these inputs are found to be incompatible with the inputs that have been obtained by simulations of other tasks or phases of the mission. In this event compromises and changes have to be made which form another loop that starts the research process over again. This cycle, in turn, may be repeated several times until an integrated system design is evolved. When this point is reached this particular research program is essentially completed. At some later date validation, hopefully, of the simulation results is obtained when the actual mission is accomplished. The flight information which is eventually obtained provides valuable background information for future simulations and is an important input to the experience which is necessary for the successful conduct of research simulation. Actual flight results provide the only valid information upon which to base changes in the simulation techniques that will improve the quality of future simulations.

TYPES OF SIMULATORS

Because each research problem generates its own peculiar simulation requirements, many kinds and varieties of simulators have been developed. Because of this great variety a number of attempts have been made to classify simulators. Although a certain amount of order has been established, these efforts have not been completely successful because, to completely describe the various simulators, it is generally found necessary to establish about as many classifications as there are simulators. However, a number of major categories have been proposed and some of the more commonly used descriptive terms are listed in figure 3. I shall not go into a detailed discussion of the pros and cons of these various types because a number of excellent papers have been published which discuss various types of simulators and the advantages and disadvantages of one kind with respect to another. Rather I would like to confine my discussion of simulator types to a few general remarks.

Most research simulators are ground-based, fixed-base, special-purpose simulators. These simulators are represented in figure 1 by the small interior "box." They generally consist of a simple chair and controls, a few essential flight instruments, and control system and vehicle dynamics generated by an analog computer. Such simulators are readily set up, operated, and maintained. They are extremely valuable for a preliminary "look" at problems. System parameters and initial test conditions can be readily varied through the analog computer, making it possible to study both normal operations and also a great variety of emergency situations. The results from these simulations, however, must be properly qualified. The simplicity of the setup, the lack of motion cues, or the absence of external visual cues may be extremely important with regard to the interpretation of the results and must always be kept in mind. When properly used, the great flexibility of these simulators makes them very valuable for research work.

Developmental simulators for a specific vehicle often start out as simulators of the kind I have just described. However, as the development proceeds other tasks and instruments are added, and also the analog computer is gradually replaced by actual hardware components. While these simulators start with the flexibility of a research simulator their evolutionary process gradually eliminates this flexibility. On the other hand, the simulator becomes more and more an exact replica of the vehicle that is under development. Most developmental simulators reach the end of their useful life when the vehicle finally goes into production and all of the hardware kinks have been eliminated. A shining exception to this situation exists in the case of the X-15 developmental simulator. This simulator is being used daily at the Flight Research Center as a training aid for the research pilots to prepare them for upcoming research flights.

Procedural and full-mission simulators also duplicate, down to the smallest detail, the characteristics and problems of an actual vehicle. This duplication is primarily with respect to the pilot or crew. Unlike the developmental simulator it generally does not contain actual hardware components but simulates the operational characteristics of the hardware by means of a very detailed computer setup. These simulators do not go through an evolutionary process such as in the case of developmental simulators. In general, these simulators are built toward the end of the research and development program when most of the details of the system have been finalized. These simulators are also extremely inflexible in terms of research use, since it is generally difficult to make major or rapid changes to vehicle or mission characteristics. However, flexibility of a sort is provided which allows a great variety of emergency situations to be simulated. The sole purpose of these simulators is to provide pilots and crews with training and experience in the detailed operation of the vehicle system.

Many research problems require that motion cues be provided to the pilot. When this is done we have, of course, arrived at moving-base simulators. A common example of a moving-base simulator is the well-known piloted centrifuge. Also in many instances it is extremely important to study the influence of out-the-window, external visual displays. Use of external visual information by the pilot and crew is becoming of great importance in space research. It is recognized that for long-duration missions complete reliance cannot always be placed on instrument indications. The great complexity and high sophistication of the electronics that are required to provide the instrumentation bring up problems of reliability. As a consequence, great effort is being put into the development of simplified guidance and control techniques, using sources of information su h as motion or visual cues which are independent of the electronic equipment, as replacement or backup procedures in order to increase mission reliability. There are many techniques available for providing motion and visual cues but I will not describe them here since this subject is discussed in a separate paper in this conference.

When several part-task simulations are combined we tend toward the development of whole-task simulators. Whole-task simulators are often required in research in order to study the compatibility problems between tasks that may in actual missions take place either in quick succession or even in parallel.

Since research problems often require either whole-task simulation, motion cues, or visual cues in an infinite variety of possible combinations it is sometimes proposed to build general-purpose simulators so as to achieve the adaptability and flexibility that are so highly desirable in research. General-purpose simulators, in the limit, try to provide all of the facilities that are diagramed in figure 1. While in principle general-purpose simulators would seem to be attractive, they do suffer from two major faults. In the first place, since they are conceived for general purposes they are not designed with a specific problem or objective in view. As a result they often are not able to handle any specific problem with the fidelity that is perhaps necessary and obtainable with a special-purpose simulator. Secondly, since most research problems do not require the simultaneous use of all of the capabilities of a general-purpose simulator, a general-purpose simulator operates almost all the time at less than maximum efficiency. For these reasons, few general-purpose simulators have been built. Generally, it is more desirable to have a few well-chosen, small facilities available. Most simulators, therefore, are originally oonstructed for specific, special purposes. This is not to say that special-purpose simulators have limited utility.

It is invariably the case that today's special-purpose simulator, designed and built to study today's special problem, becomes tomorrow's special-purpose simulator for tomorrow's problem through generally minor modifications. Few instances are known where special-purpose simulators have lost their usefulness and had to be abandoned.

An overwhelming percentage of research simulators are ground based. In certain situations, however, ground-based simulators can never provide the fidelity required. These situations generally are concerned with problems of landing and touchdown. These problems are best handled by flight-test simulators. Ground-based simulators, no matter how sophisticated they may become in providing visual or motion cues, will probably never be able to realize the degree of realism and be able to generate the motivation that is required to obtain adequate answers in these situations. This can be obtained only by putting the pilots in a true flight environment.

It would seem to be a simple matter to distinguish between ground-based and flight-test simulators. However, later on I shall describe a simulator which is rather difficult to classify as one or the other. I mention this now only, in concluding this short discussion of various types of simulators, because further discussion of the subject is best handled by a discussion of various problem areas and then describing the simulators that are being used and are best suited to study of these problems.

MANNED-SPACE-MISSION PHASES

The major phases of a typical manned space mission are shown in figure 4. Each mission begins with an earth launch, followed by the establishment of an earth orbit. After establishment of earth orbit, orbital operations take place.

These operations may consist of nothing more than final checkout before injection into an interplanetary trajectory. In our more ambitious follow-on missions, however, these operations may involve rendezvous, docking, orbital assembly, extra-vehicular activities, etc. The midcourse and return portions of interplanetary flights will require from days to perhaps months of operations involving relatively little activity. Activity will be restricted primarily to navigation, onboard maintenance, and perhaps onboard simulations in order to maintain proficiency in accomplishing end-point maneuvers. When the planetary objective is reached, the mission phases involved may include orbit establishment, letdown and landing, surface operations, launch, rendezvous and docking, and, finally, injection into a return trajectory. Upon return the phases which terminate the mission include reentry, landing, and touchdown. Each of these various phases have their own special problems and requirements; and for this reason special-purpose simulators are used to study these problems.

EARTH LAUNCH AND REENTRY

Earth launch and reentry are characterized by a gradual build up in longitudinal acceleration. In launch the acceleration may reach as high as 6g or 8g, and in reentry the acceleration level may approach 12g to 16g. In the case of launch this longitudinal acceleration profile may be repeated two or three times at each system stage. Lateral and angular accelerations will also be present and these may reach significant magnitudes and frequencies. Although to date all earth launches have been under automatic control, there is growing interest in the development of manual-control techniques. Manual control of large conventional boosters may offer benefits in reliability and also in safety when emergency situations arise. Manual control may also assume great importance when we consider maneuverable and recoverable boosters.

One type of simulator which has been used extensively in studying launch and reentry problems is the human centrifuge. An example of this type of simulator which has been used effectively is the Ames five-degree-of-freedom simulator shown in figure 5. Although the g-level obtainable is somewhat restricted (6g at full speed) this level has been adequate for many situations. High angular accelerations are available (18 radians per second per second in roll, 6 in pitch, and 12 in yaw) and are adequate to duplicate most vehicle performance. The Ames centrifuge is unique in that gimbal motions are powered by chain-belt drives attached to sprockets mounted to the motor shaft and moving around the rubber-based gimbal rings. One of these drives is shown in figure 6. This type of drive eliminates gear weight, noise, and backlash and allows for the use of a high-speed low-weight motor. Another novel feature is that the centrifuge arm is driven by an endless steel cable wrapped around the outside of the track and picked up and laid down by pulleys mounted on the arm. This drive is shown in figure 7. The advantage of this type of drive is that it avoids the cost of large gears or high-torque electrical motors. On the other hand, the track noise has been somewhat of a problem since it furnishes an unwanted cue to the pilot which informs him of the application of a side force before he feels the force itself. Efforts are being made to reduce this track noise to lower levels. These centrifuges are very worthwhile in the development of cockpit layouts, controllers, and pilot restraint systems so that the pilot can perform adequately under these acceleration conditions. When this equipment is properly designed it has generally been found that adequate pilot performance can be maintained under practical mission conditions.

Centrifuges are furthermore often useful in uncovering unusual problems. One recent launch simulation, for example, showed that a particular structural frequency was such as to make it impossible for the pilot to read his instruments.

RENDEZVOUS

Visual rendezvous may start as far as 200 miles from the target and terminates as the target acquires some size and detail. One simple, economical simulator which was assembled 4 years ago to study visual rendezvous problems is shown in figure 8. This facility is the Langley inflatable planetarium. This planetarium is nothing more than a surplus Air Force inflatable radar dome. Although the interior is dark and unpainted, this surface has been found to be satisfactory since it is required only to be able to see a star field, a point light (probably flashing) for the target, and perhaps an horizon for gross orientation. When the pilot is dark-adapted, these visual features are clearly discernible. This type of projection surface, however, would not be adequate for the simulation of approach or landing where more detail must be displayed. A typical hardware arrangement used in visual-rendezvous studies is shown in figure 9, which shows a setup made for studying Gemini/Agena problems. The mock-up Gemini half-cockpit can be seen and behind it the equipment for generating the visual displays. This equipment consists of a star-field projector, a target projector, and an horizon projector. These are mounted on a surplus Nike-Ajax radar drive, modified by the addition of a third axis. We have, incidentally, found this radar drive to be readily adaptable to analog simulation work and it is being used not only here but in a number of other simulations at Langley. A closeup view of a typical star-field projector is shown in figure 10.

The projector operates on a concept developed by Spitz. It consists of a point-light source reflecting off a centrally located highly reflective sphere which directs the light outward through the many holes representing the stars. The size of the holes is varied to vary star magnitude. The star images are brought to a focus on the inside of the planetarium by lenses glued to the surface of the projector. Simple geometric relationships such as the size of the projector and the diameter of the projection sphere govern the focal length required for these lenses. Although this type of projector does not have the precision required for the study of navigation problems it is very adequate for pilot control problems such as rendezvous where the star field is primarily used as an attitude reference.

DOCKING

Docking operations are considered to start when the pilot first can discern vehicle target size and aspect and terminate, of course, when soft contact is made. One unusual docking simulator that has been in operation at Langley for the past year is shown in figure 11. This Rendezvous Docking Simulator employs full-scale mock-ups of spacecraft cockpits mounted in gimbals. This facility is unique in that the entire gimbal assembly is supported by a cable system attached to an overhead crane. The unique cable arrangement effectively rigidizes the system and avoids pendulous motion so that correct linear motions can be commanded. A novel lightweight hydraulic-pneumatic counter-balance system is used to support the gimbal assembly. This permits the use of a relatively small vertical-drive motor which has only to overcome the inertia of the hanging system. The facility enables simulation of the docking operation from a distance of 200 feet to actual contact with the target. A full-scale mock-up of the target vehicle is suspended near one end of the track. An Agena target used in recent studies is shown in figure 12. On this we have mounted the actual Agena docking mechanism and also various types of visual aids. We have been able to devise visual aids which have made it possible to accomplish nighttime docking with as much success as daytime docking. Many of the astronauts have flown this simulator in support of the Gemini studies and they, without exception, appreciated the realism of the visual scene. The simulator has also been used in the development of pilot techniques to handle certain jet malfunctions in order that aborts could be avoided. In these situations large attitude changes are sometimes necessary and the false motion cues that were generated due to earth gravity were somewhat objectionable; however, the pilots were readily able to overlook these false motion cues in favor of the visual realism.

Another docking simulator which uses closed-circuit television techniques is also in operation at Langley and is shown in figure 13. In this Visual Docking Simulator a small-scale model of the target vehicle having three degrees of freedom is mounted in front of the 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 pilot's head and is projected in correct size on the inside 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 crew are seated in a full-scale mock-up of the Gemini cockpit. The small scale of the target model and the loss in resolution through the TV system made the visual realism of this simulator considerably poorer than the realism that was achieved in the Rendezvous Docking Simulator. On the other hand, this simulator did not introduce any false motion cues. This simulator also has a much larger operating volume than does the other docking simulator. Therefore it is particularly useful in study of such problems as in-close inspection of uncooperative targets, for example. For docking studies the lack of three-dimensionality inherent in these closed-circuit TV systems or other projection-type systems is a distinct handicap. This handicap is reflected in the fact that more training on this simulator was required to reach the same proficiency in docking than with the Rendezvous Docking Simulator.

The Visual Docking Simulator had an extremely wide field of view. Other simulators have been constructed to study docking problems which used small-size viewing screens with CCTV or image-generation systems of the type shown in figure 14. This type of docking simulation, with restricted field of view, places unnecessary restrictions on the pilot since he has to provide more attitude control than necessary in order simply to keep the target in view. Because of this restriction he requires more fuel than necessary and the results of studies with this type of equipment may, in this respect, be misleading.

ONBOARD SIMULATORS

The small field of view available from these types of display systems may be a restriction that will have to be accepted for onboard simulators. Onboard simulators are considered to be necessary for long-duration missions in order to maintain pilot proficiency for the accomplishment of intricate maneuvers either at the mission objective or upon return. The limitations that may have to be accepted for onboard simulators must be carefully evaluated and, if possible, new techniques for overcoming these limitations may have to be devised.

ORBITAL OPERATIONS

Orbital operations, insofar as pilot or crew are concerned, include such activities as extra-vehicular locomotion, orbital assembly, and astronaut retrieval in the event that malfunctions occur. Extra-vehicular locomotion problems are now being studied through the use of in-flight simulators wherein airplanes fly zero-g trajectories as shown in figure 15. At the present time this technique is the only one that we have available which permits six-degree-of-freedom maneuvering. It is severely restrictive, however, in that the period of weightlessness is limited to something less than one-half minute. The initial high-acceleration pull-up and the necessity for securing the test equipment and test subjects in order to withstand the final pull-out are also complicating factors. Perhaps the most serious limitations in this technique are due to the Coriolis forces that cannot be eliminated and to the fact that the reference frame of the experiment is continually shifting because of the airplane pilot's maneuvers in attempting to hold the zero-g trajectory. A better simulation technique to study these types of problems would be highly desirable.

Extra-vehicular locomation will probably always be accomplished with the astronaut tethered to his vehicle by a safety cable. Should some emergency occur it will be necessary to retrieve the astronaut through this cable. The problem of astronaut retrieval is not simple, as shown in figure 16. If the astronaut is only a few thousand feet from his vehicle and has only a slight lateral velocity with respect to his vehicle when the malfunction occurs conservation of angular momentum during the reel-in process results in very unsatisfactory conditions on contact. In order to avoid these problems much more sophisticated concepts than simple reel-in are required. Unlike the extra vehicular locomotion problem which is three dimensional the retrieval problem can probably be reduced to two dimensions. In this respect, then, the development of simulators to study this problem may be simpler. It may be possible, for example, to develop small ground-effects machines that can simulate the problem. One type of tethering simulator, on a small scale, is shown in figure 17 as proposed in a recent study contract to Langley on the retrieval problem. A preliminary setup of this type of simulator has been built at Langley and this approach appears feasible.

Orbital assembly may require that astronauts move large masses either through their own efforts or with the assistance of self-contained, readily attachable propulsion modules (small space tugs) which they directly or remotely control. Techniques for realistically simulating these situations are nonexistent. This simulation problem appears even more difficult than the extra-vehicular locomotion problem

LUNAR ORBIT, LANDING, APPROACH, AND TAKE-OFF OPERATIONS

The guidance and control systems for tasks to be accomplished in the vicinity of the moon should be as simple and reliable as possible. Although a number of part-task simulators have been used to study various aspects of lunar operations, it is necessary to have some facility that can study the whole-task problem in order to arrive at an optimum integrated system. For this purpose there is under construction at Langley a new facility called LOLA, which stands for Lunar Orbit Landing and Approach Simulator. This simulator is shown schematically in figure 18 and consists of a pilot's capsule, a closed-circuit TV complex, 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, two spherical segments, and one flat section. The models are arranged so that only two camera transport mechanisms and two closed-circuit TV systems are needed to view the four models. A photograph of LOLA under construction is shown in figure 19. The heart of LOLA will be the optical pickup. The system which is currently scheduled for installation is shown schematically in figure 20. The lunar surface is viewed through a single wide-angle 220° lens. This single view is then operated on electronically to provide the various vehicle motions. Midway through the system the single scene is projected on a television screen and viewed by four pickup cameras. These four pickup cameras then, in turn, project their separate views through the four portholes of the space vehicle so that the view from each porthole will correspond to the view that the pilot will see.

Simulators somewhat similar to LOLA are being used or are under construction in industry. A view of what the pilot might see in this type of simulator is shown in figure 21, which pictures the Boeing simulator. This figure, incidentally, also illustrates one limitation of this general class of visual display system. This limitation is the loss in detail and resolution as the model is closely approached. While simulators of this type will be extremely valuable in studying problems where close maneuvering is not required (such as in orbital operations and the initial phases of landing), the lack of detail and the absence of three-dimensional effects preclude the effective use of these facilities for the final landing and touchdown situations. These problems can be studied most effectively through actual flight-test simulators.

Sometimes used in another simulation technique which attacks the problem in a different way from LOLA. Shown in figure 22 is a view of the Ryan simulator. This simulator makes use of a point-light-source projection technique.

As can be seen, the large transparency is hung above the pilot's head. This transparency is driven through a computer in response to the pilot's control inputs so that the scene shifts properly. The scene is projected in front of the pilot on a spherical screen by a point-light source shining through the transparency. This simulator has been used very effectively in the study of helicopter and VTOL problems and could equally well be used in the study of space vehicle problems. It is, however, similar to the other simulators just discussed in being affected by the loss of detail as the scene is closely approached. For this reason this type of simulator is generally used primarily for the initial landing and maneuvering phases and not for actual close-contact problems.

LUNAR SURFACE OPERATIONS

When the astronauts land on the moon they will be in an unfamiliar environment involving, particularly, a gravitational field only one-sixth as strong as on earth. A nevel method of simulating lunar gravity has been developed and used at Langley to study the problems of how to walk, run, or jump on the moon. The Lunar Walking Simulator is shown in figure 23. As you can see, the subject is supported by a puppet-type suspension system at the end of a long pendulum. A floor is provided at the proper angle so that one-sixth of the subject's weight is supported by the floor with the remainder being supported by the suspension system. This simulator allows almost complete freedom in vertical translation and pitch and is considered to be a very realistic simulation of the lunar walking problem. For this problem this simulator suffers only slightly from the restrictions in lateral movement it puts on the test subject. This is not considered a strong disadvantage for ordinary walking problems since most of the motions do, in fact, occur in the vertical plane. However, this simulation technique would be severely restrictive if applied to the study of the extra-vehicular locomotion problem, for example, because in this situation complete six degrees of freedom are rather necessary. This technique, in effect, automatically introduces a two-axis attitude stabilization system into the problem. The technique could, however, be used in preliminary studies of extra-vehicular locomotion where, for example, it might be assumed that one axis of the attitude control system on the astronaut maneuvering unit may have failed.

ROTATING SPACE-STATION OPERATIONS

The simulation technique just described can be applied to the study of locomotion in a rotating space station. A rotating space-station simulator concept is shown in figure 24. As may be seen the test subject is hung in the sling support and suspension so that he is initially in a zero-g condition. Then the entire suspension system and the space station are rotated so that artificial gravity is supplied through centrifugal force.

LUNAR LANDING

Ground-based simulators are not very satisfactory for studying the problems associated with the final phases of landing and for this reason it is preferable to go to some sort of flight-test simulator. One research facility designed to study the final phases of lunar landing is now in the checkout phase at Langley. This Lunar Landing Research Facility is shown in figure 25. Because of its large size it is difficult to get a good picture of this facility so an artist's conception is presented. The facility is an overhead crane structure about 250 feet tall and 400 feet long. The crane system supports five-sixths of the vehicle's weight through servo-driven vertical cables. The remaining one-sixth of the vehicle weight pulls the vehicle downward simulating the lunar gravitational force. During actual flights the overhead crane system is slaved to keep the cable near vertical at all times. A gimbal system on the vehicle permits angular freedom for pitch, roll, and yaw. The facility is capable of testing vehicles up to 20,000 pounds. A research vehicle, weighing 10,500 pounds fully loaded, has been constructed and is shown in figure 26. This vehicle is provided with a large degree of flexibility in cockpit positions, instrumentation, and control parameters. It has main engines of 6,000 pounds thrust throttleable down to 600 pounds and attitude jets. This facility will be able to study the problems of the final 200 feet of lunar landing and the problems of maneuvering about in close proximity to the lunar surface. It will not, however, be able to study the important problems of transition from the letdown operation to the final touchdown phase. With regard to type of simulator, this facility may be described as five-sixth ground-based and one-sixth flight-test. It will be subject to the same vicissitudes of weather conditions as flight-test vehicles and also it must be designed with safety precautions to counter the hazards that exist in all types of flight research.

Another simulator for studying the lunar landing problem is in the final assembly and checkout stage at the NASA Flight Research Center. This simulator is shown in figure 27. The vehicle is being built by Bell Aerosystems and contains a gimbaled jet engine which provides an upward force along the gravity vector that equals five-sixths of the vehicle's earth weight. Rocket engines are used to decelerate the vehicle, provide stability and damping, and for maneuvering. This simulator will be extremely valuable for investigating problems associated with the final three to four thousand feet of the lunar landing operation. This will take the operation through the very critical transition phase from final approach to actual soft letdown to the lunar surface. As is the case with every flight-test simulator, this vehicle suffers from a certain amount of inflexibility in that it is difficult to make configuration changes. It is also, of course, subject to the usual hazards of flight-test research and to the extraneous factors of wind and weather conditions which do not exist on the moon.

EARTH LANDING

The problem of studying earth landings, particularly with some of the rather unconventional configurations that are now being proposed makes the use of flight-test simulators necessary. Lightweight glide vehicles of the type shown in figure 28 have proved extremely valuable in studying some of the problems that arise in landing these unusual space vehicles. These types of simulators have proved to be low cost and have required a relatively short time to put into operation. This technique of building manned flying models of space vehicles for study under actual flight conditions is now being extended, and somewhat more sophisticated vehicles are being built. Several are now under construction by the Northrop Corporation. They will be launched from a B-52 at high subsonic speeds. Installation of small rocket engines in order to drive them to supersonic speeds is also being considered. These vehicles are being built at a cost which compares very favorably with the more complex ground-based simulators and will undoubtedly do a better job of simulation.

WHOLE MISSIONS

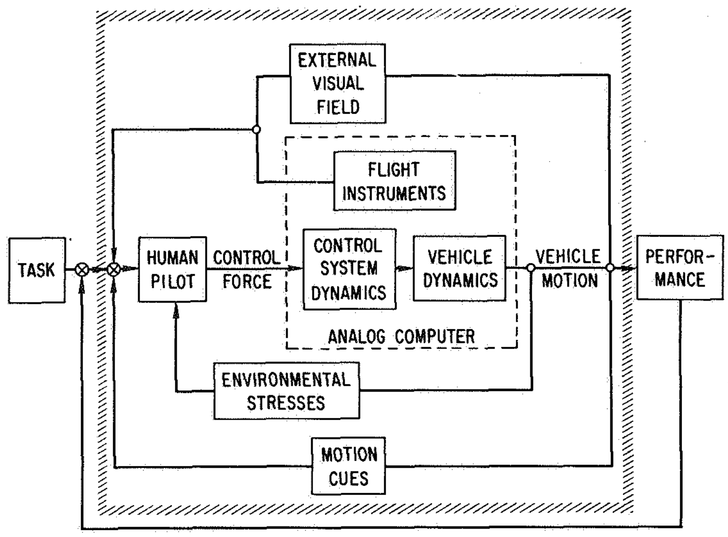
One type of whole-mission simulator is being planned by the Ames Research Center and is called the Space Flight Guidance Research Facility. This is a research simulator designed to study the whole-mission problems taking into account many of the physiological factors that may be of importance. As such it is being designed primarily as a centrifuge. A photograph of the model of the centrifuge is shown in figure 29. The centrifuge will provide the capability of simulating the acceleration conditions during launch and reentry. During midcourse operations the centrifuge will be brought to rest next to an adjacent facility which will allow the crew to perform midcourse navigation and control tasks under realistic visual conditions. The unique feature of this facility will be that the gimbaled three-man cab will be provided with life-support equipment so that long-duration missions can be simulated in real time. As a research facility this simulator will be provided with a great deal of flexibility through the capabilities of the centrifuge, the life support system, the navigation and guidance equipment, and the associated computer complex.

Another type of whole- or full-mission simulator is shown as an artist's concept in figure 30. This simulator, designed primarily for astronaut training purposes, is being constructed at the Manned Spacecraft Center in Houston. As you can see, this Apollo Mission Simulator will contain a complex of visual display systems to provide realistic out-the-window views for the various phases of the mission. The Apollo systems and equipment will be simulated with the aid of a large complex of computing equipment to provide a realistic operation environment to the crew. As is characteristic of these types of full-mission simulators no attempt will be made to give the pilot any motion cues.

This type of full-mission simulator, or procedures trainer, has proven very valuable. In the case of the Mercury program, the Procedures Trainer was very effective in training the astronauts to handle both normal and the emergency situations which, as everyone knows, did arise.

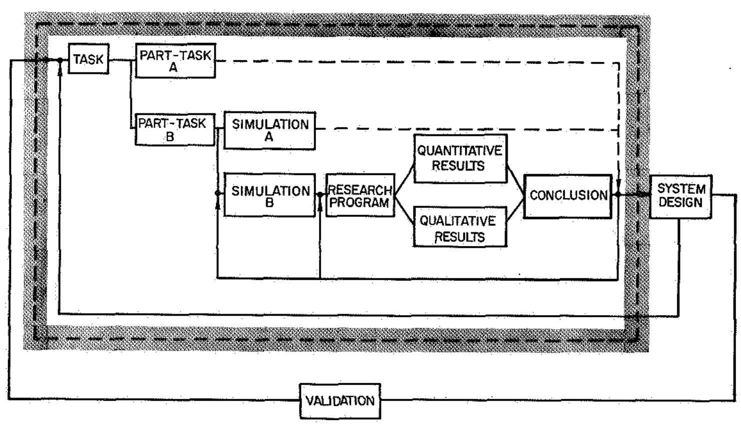
CONCLUDING REMARKS

Flight simulation in space research is assuming a more important role than it had in aeronautical research. In our space programs every effort has to be made to solve all of the possible problems before first flight. The space program does not have the opportunity to conduct developmental flight testing for hours and hours before the final vehicle goes into service use. The only way this intensive development can be carried out is through the use of simulation. As I have tried to show, our flight simulators come in all shapes and sizes due to the great variety of our space problems. Some of these facilities must be highly sophisticated. Well-conceived facilities and well-directed simulation programs are required to provide timely answers to the many new problems peculiar to space-flight missions.



NASA

Figure 1.- Piloted flight simulator.



NASA

Figure 2.- Research simulation process.

GROUND-BASED	FLIGHT TEST
FIXED-BASE	MOVING BASE
PART TASK	WHOLE TASK
SPECIAL PURPOSE	GENERAL PURPOSE
RESEARCH	PROCEDURAL
DEVELOPMENTAL	FULL MISSION

NASA

Figure 3.- Types of simulators.

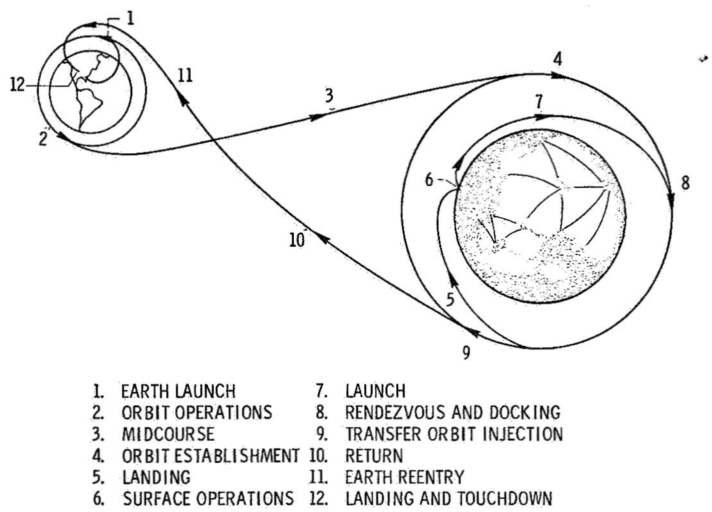


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Figure 4.- Manned space-mission phases.

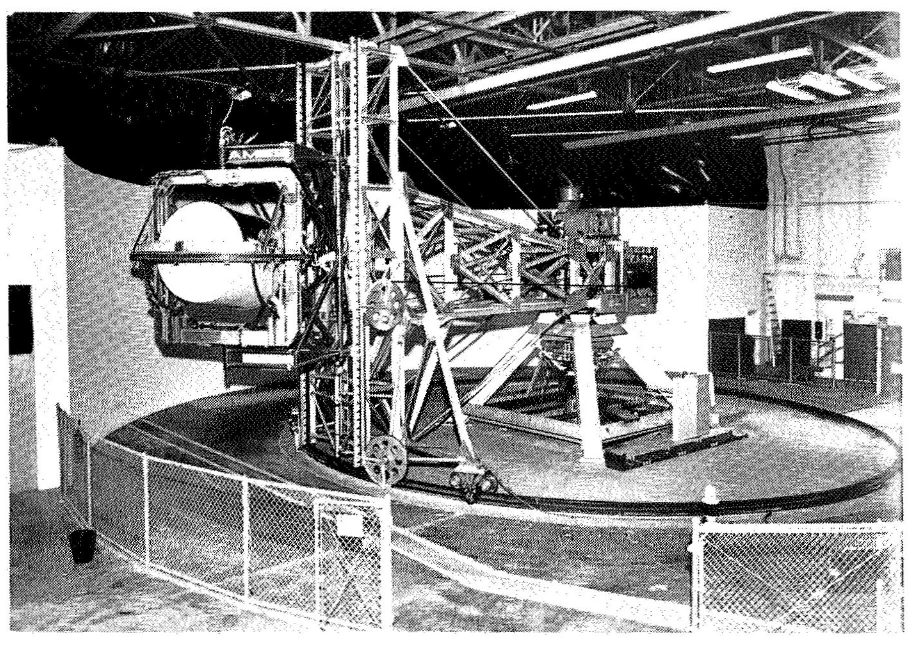

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Figure 5.- Ames five degree of freedom simulator.

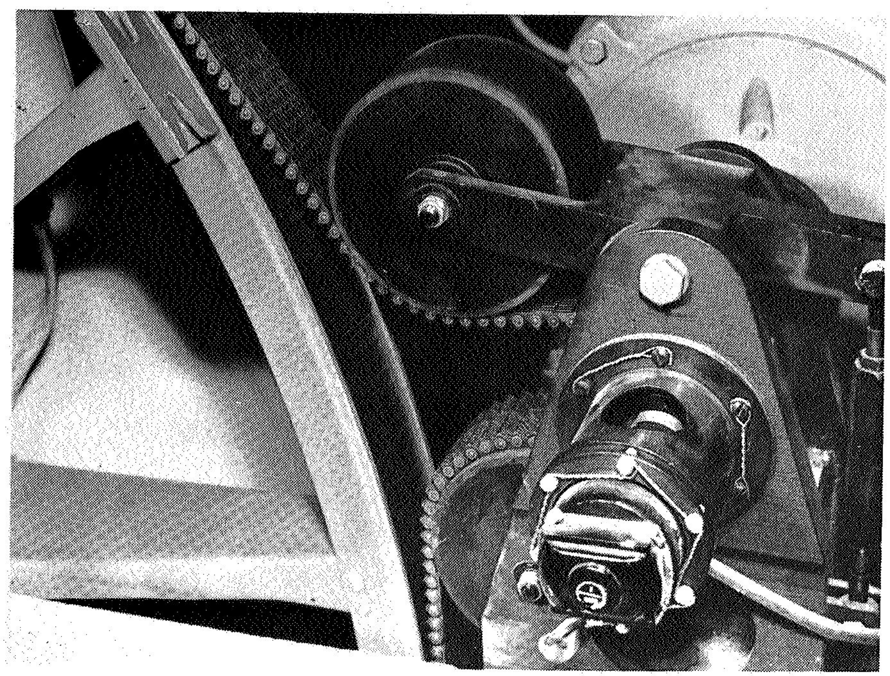

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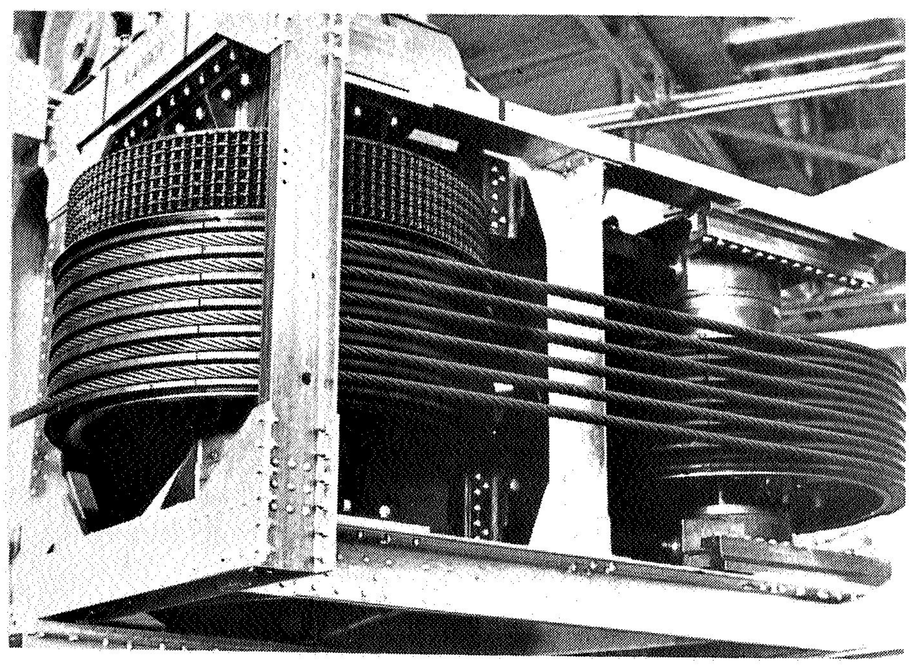
Figure 6.- Silent chain belt drive.



NASA

Figure 7.- Cable drive.

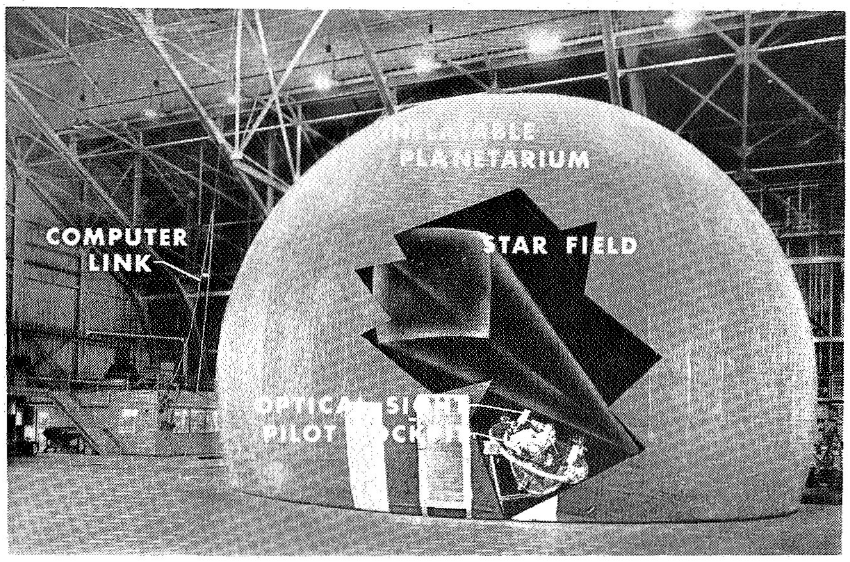


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Figure 8.- Visual Rendezvous Simulation.

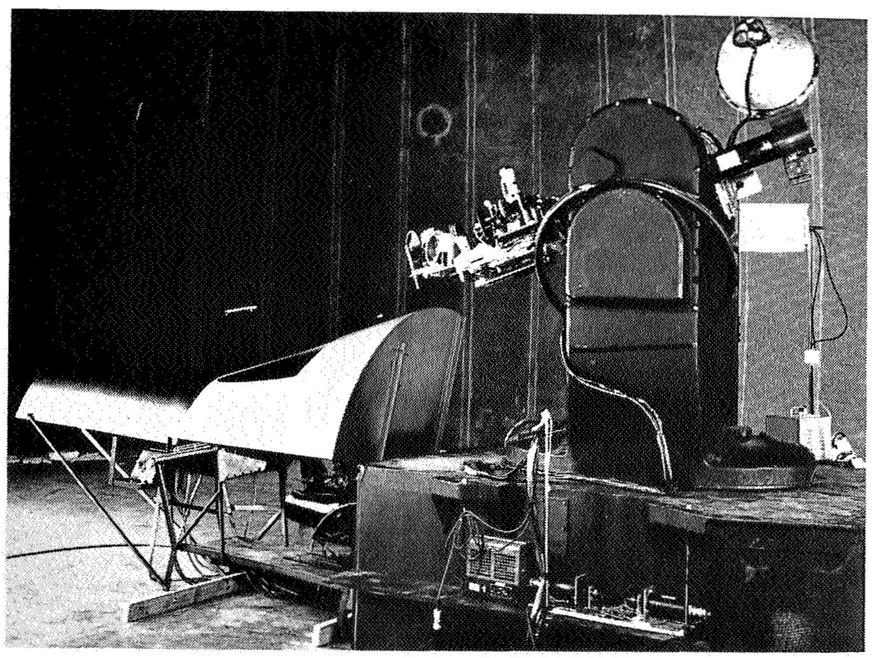

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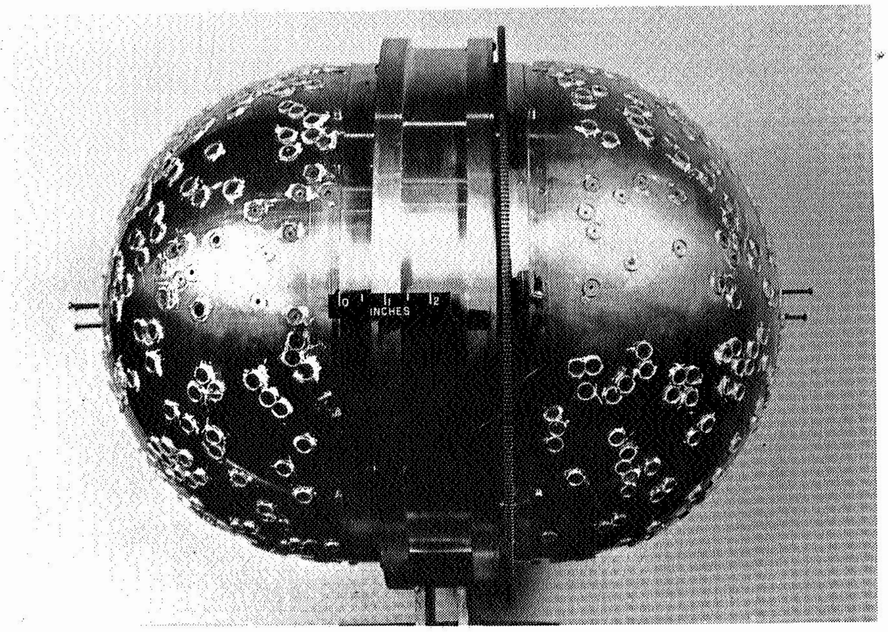
Figure 9.- Visual rendezvous equipment.



NASA

Figure 10.- Star projector.

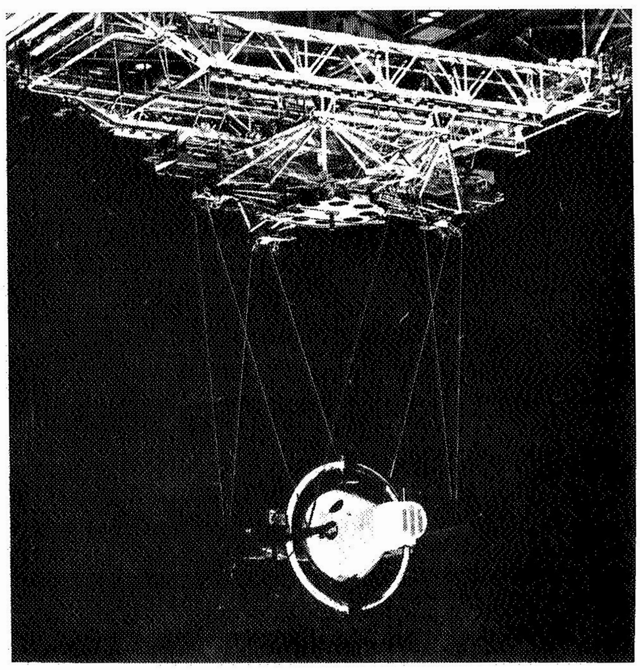


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Figure 11.- Rendezvous docking simulator.

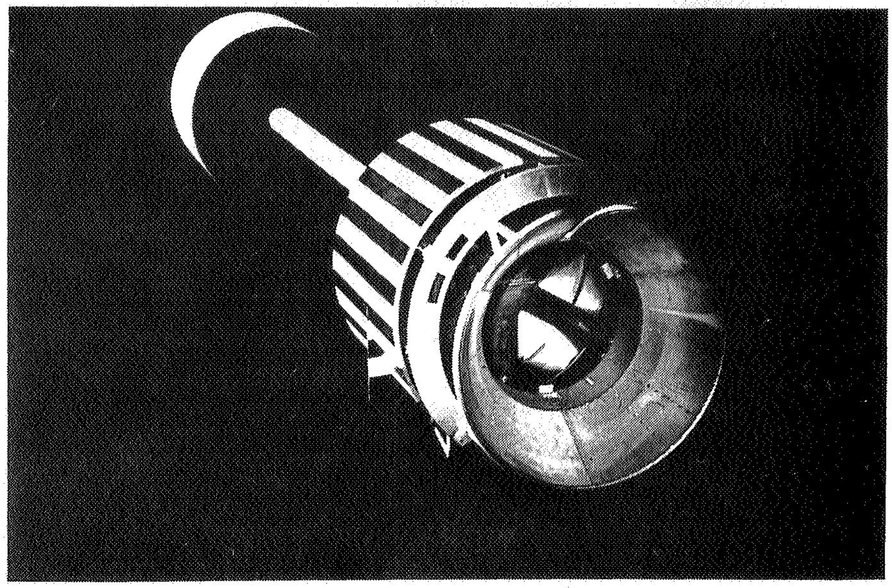

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Figure 12.- Docking target.

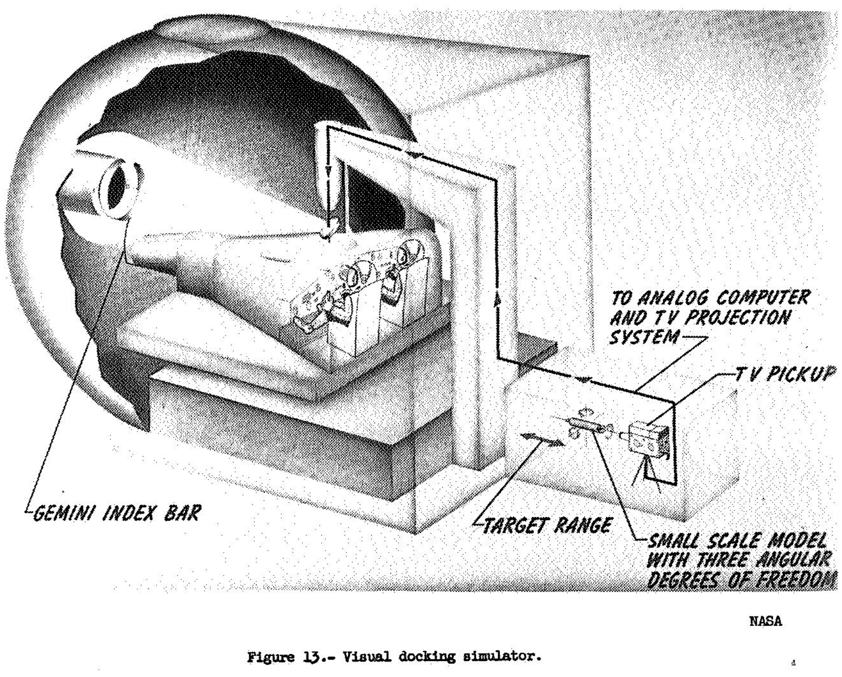

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Figure 13.- Visual docking simulator.

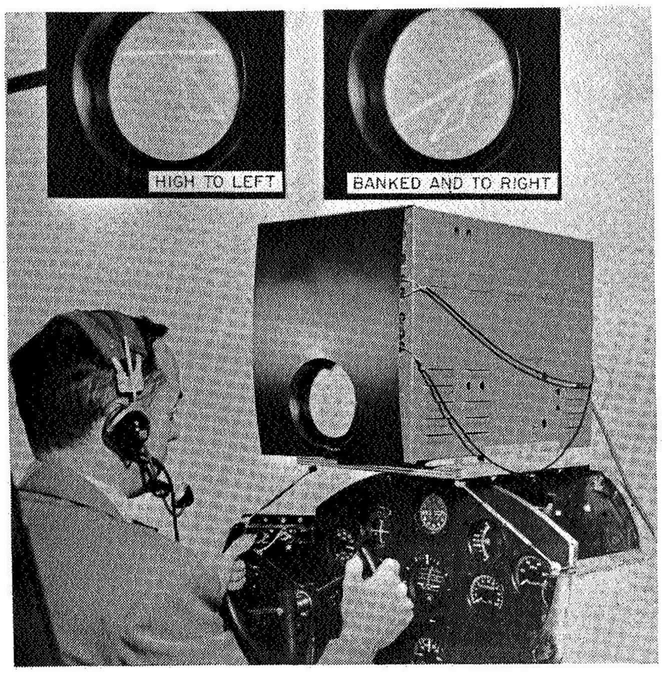

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Figure 14.- Image generator.

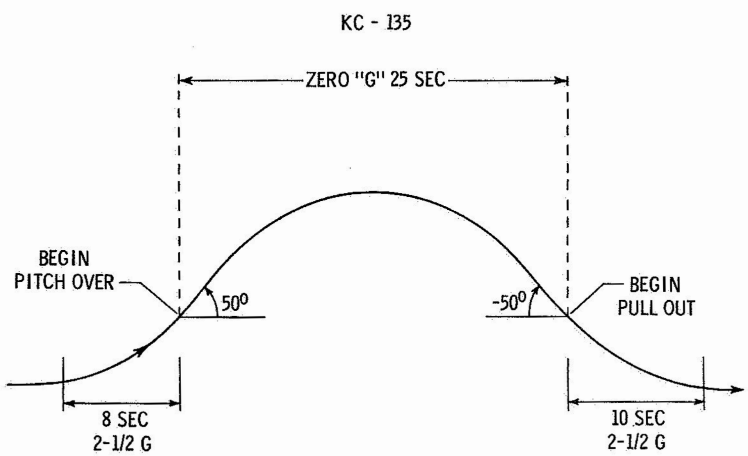

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Figure 15.- Zero-"G" trajectory.

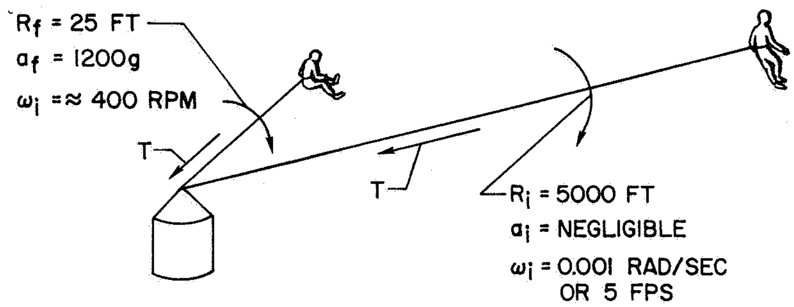

Figure 16.- Astronaut retrieval.

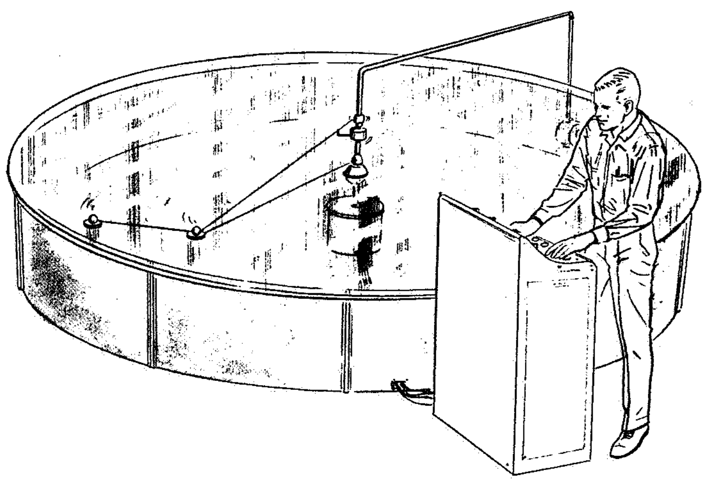

Figure 17.- Scale model controlled tethering simulator.

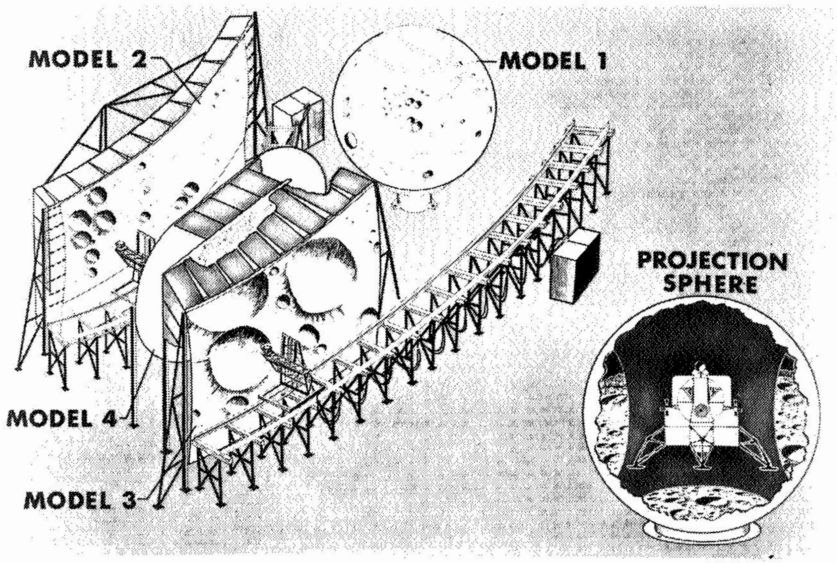

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Figure 18.- Lunar orbit landing approach.

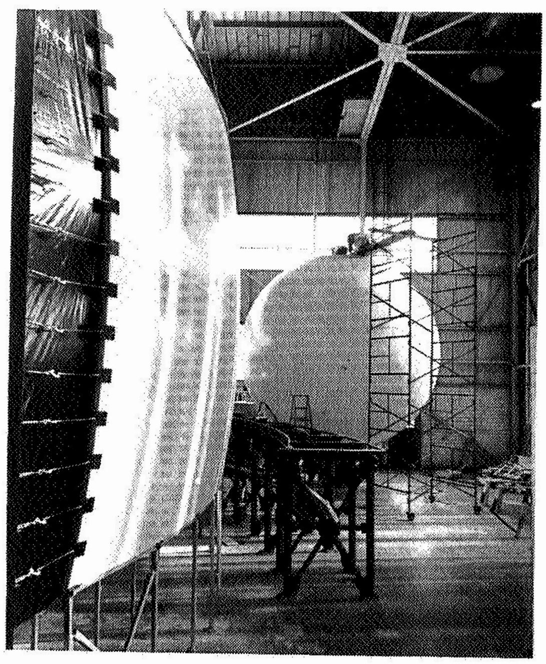

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Figure 19.- LOLA construction.

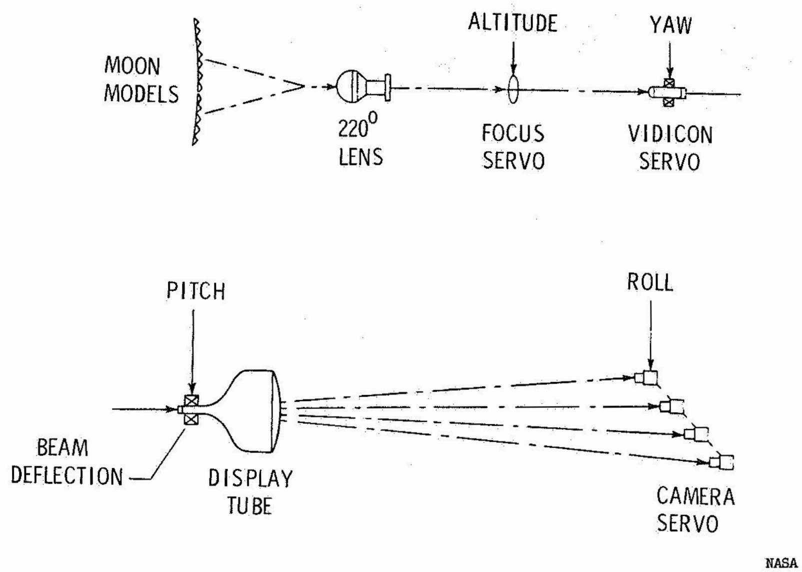

Figure 20.- LOLA optical pickup.

Figure 21.- Pilot's view.

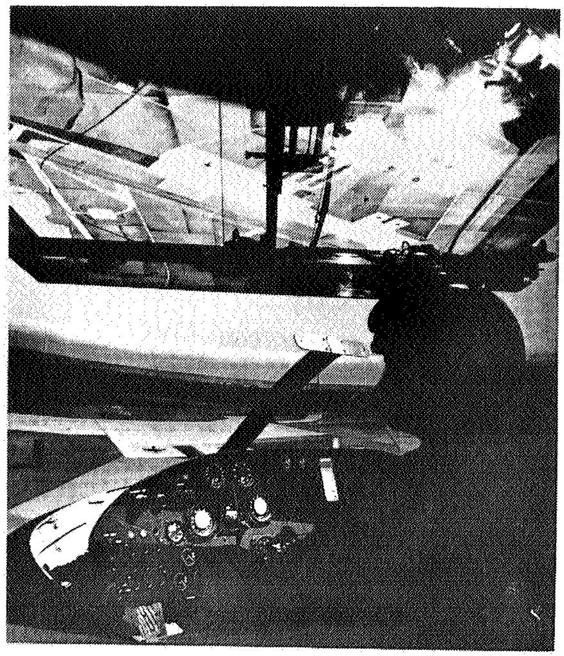

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Figure 22.- Ryan simulator.

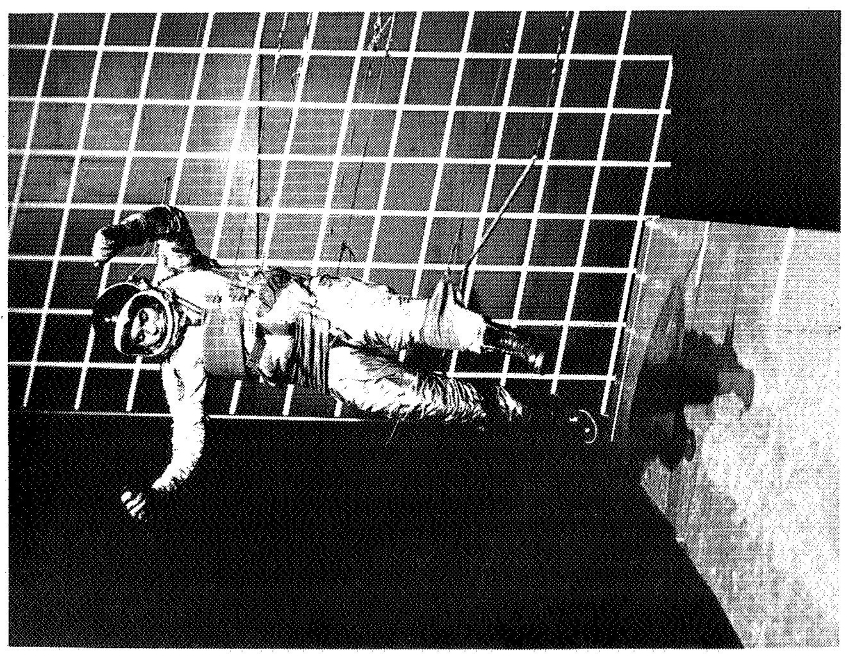

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Figure 23.- Lunar walking simulator.

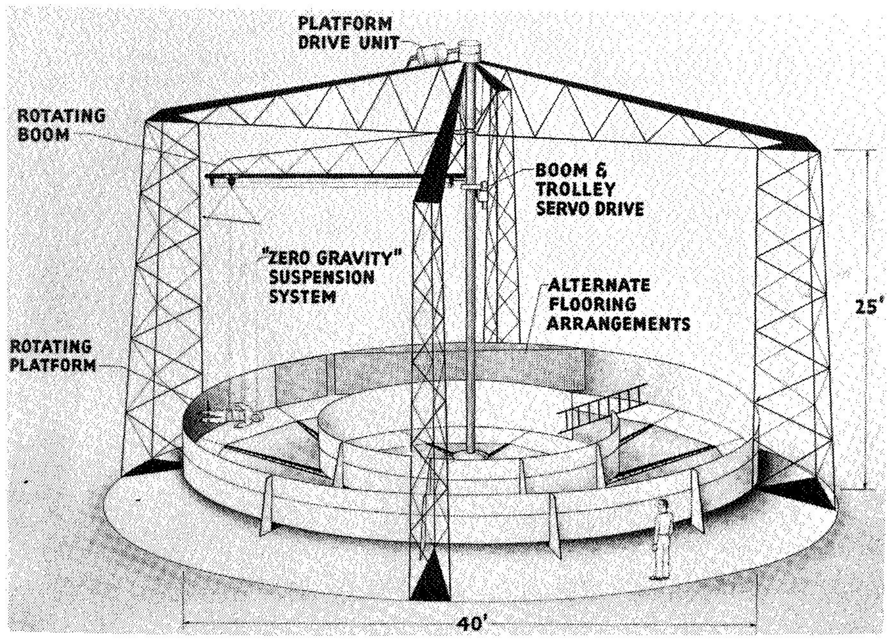

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Figure 24.- Rotating space station simulator.

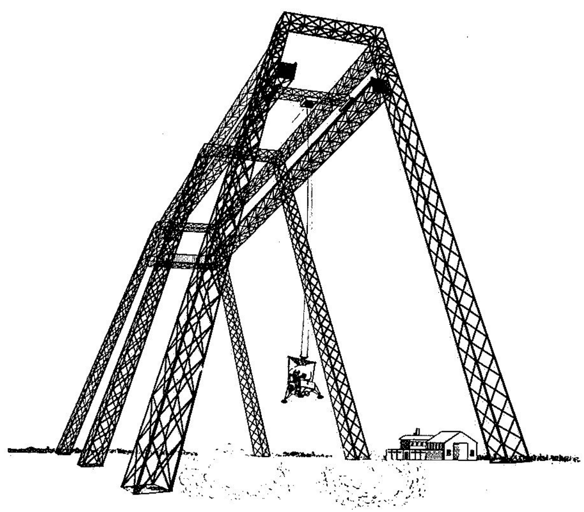

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Figure 25.- Langley lunar landing research facility.

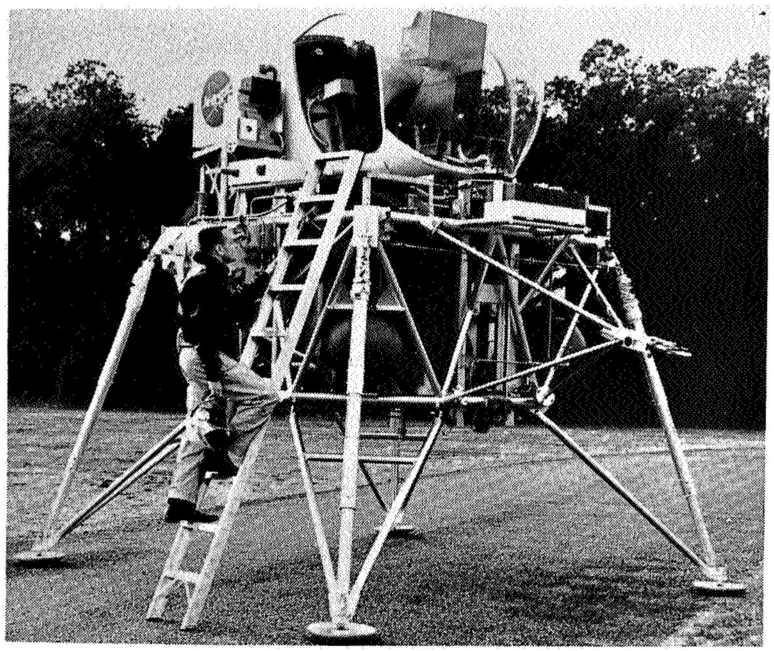

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Figure 26.- Research lunar lander.

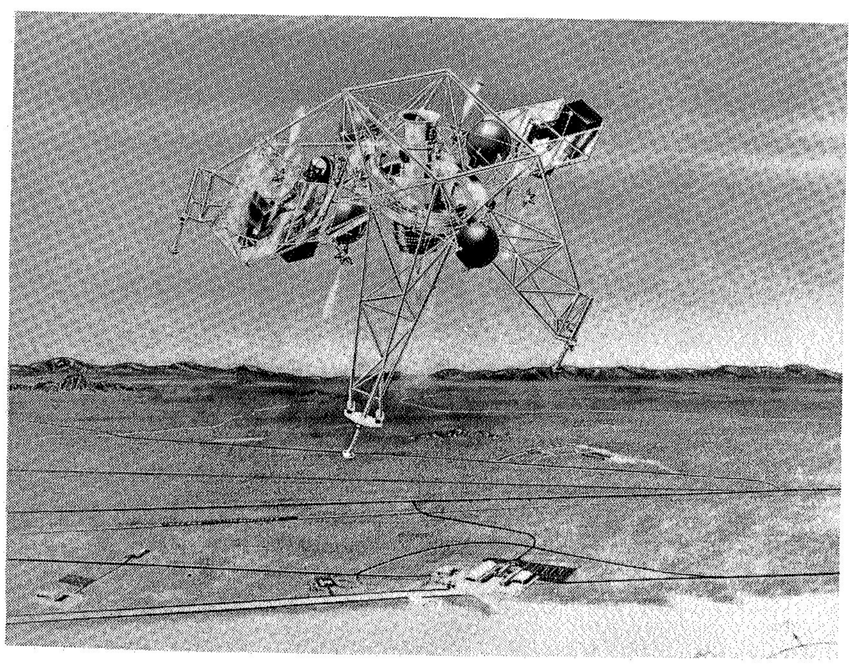

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Figure 27.- Lunar landing research vehicle.

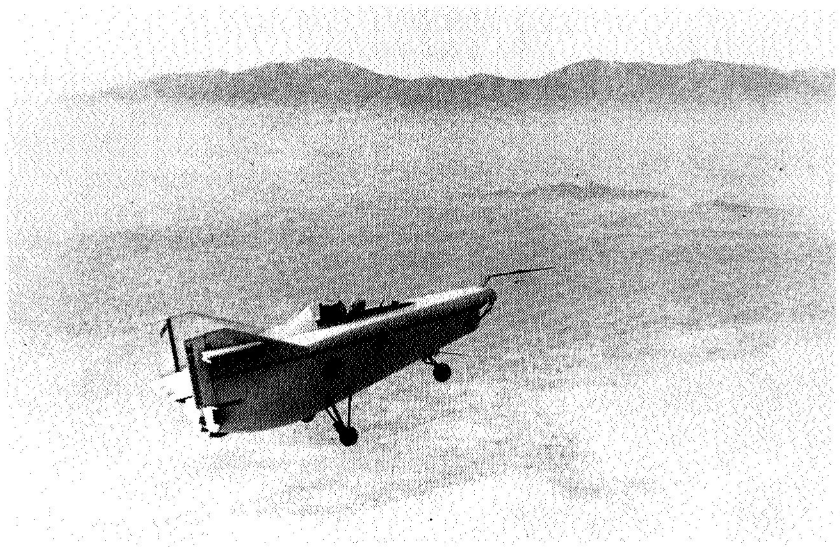

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Figure 28.- Lightweight M-2.

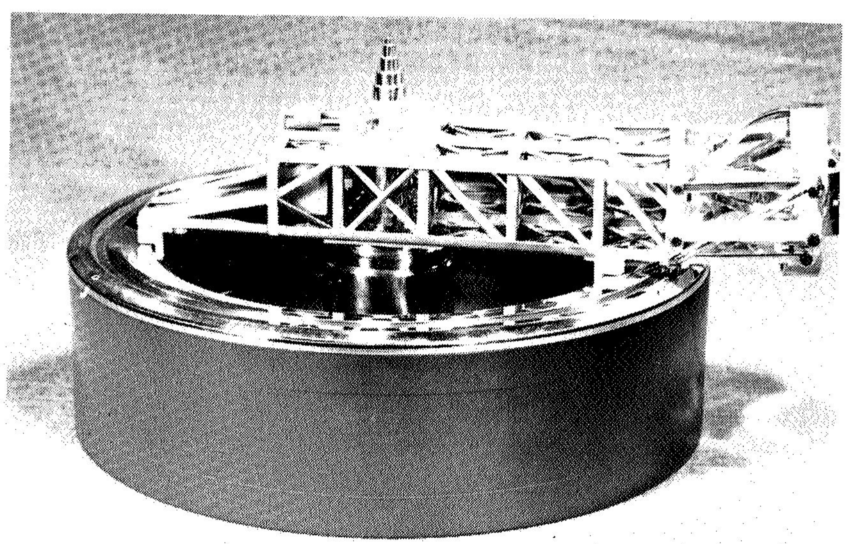

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Figure 29.- Ames space flight guidance simulator.

APOLLO MISSION SIMULATOR
LINK PHOTO

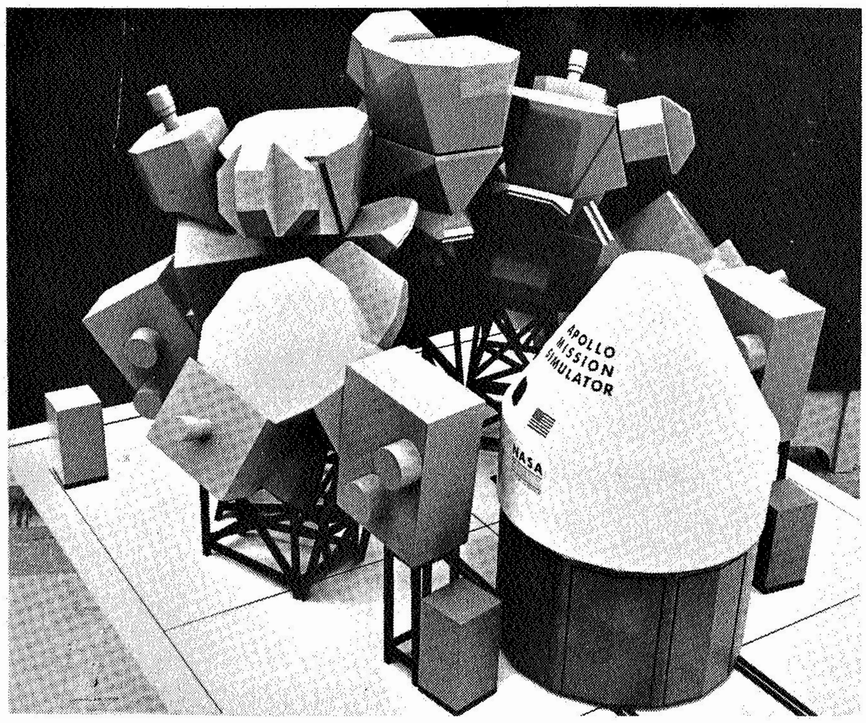

Figure 30.- Apollo mission simulator.

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