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VISUAL SIMULATION FACILITY FOR EVALUATION OF LUNAR SURFACE ROVING VEHICLES

by F. L. Vinz, M. H. Knighton, H. F. Lahser,
L. G. Thomas, J. T. Howell, and J. S. Spear

George C. Marshall Space Flight Center
Huntsville, Ala.

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VISUAL SIMULATION FACILITY FOR EVALUATION OF LUNAR SURFACE ROVING VEHICLES

SUMMARY

A fixed base visual simulator was developed by the Simulation Branch of the Computation Laboratory, Marshall Space Flight Center to serve primarily as an engineering tool which would include man-machine interaction in evaluations of preliminary Lunar Surface Vehicle design.

Visual cues are obtained by means of a U.S. Air Force SMK-23 visual simulator consisting of a camera and model unit and a projector and screen providing a 30° x 50° field-of-view of a three-dimensional terrain model.

The crew station consists of a general-purpose two-man cockpit designed for maximum flexibility. The crew station and the general-purpose analog computers are interconnected through an interface console featuring a removable patch panel and containing power supplies, relay racks, servo panels, limiters, and other items common to most simulators.

The terrain model is scaled 150:1 and has a maximum dimension of 12 x 27 feet. Maximum camera-model separation is eight inches. Lunar surface details required in the manufacture of the model were reduced from Ranger VIII photographs and supplied by the Branch of Astro-Geology.

Terrain surface irregularities are detected by sensors mounted around the camera optics.

I. INTRODUCTION

The responsibility of MSFC in the Apollo Applications Program has included development studies of lunar flying vehicles, lunar surface roving vehicles, and certain scientific experiments that will be conducted on the surface of the moon. These development studies have been conducted both in-house at MSFC and in contracted studies.

Development of lunar surface roving vehicles began with two parallel competitive contracts for the preliminary design of mobile laboratory vehicles by the Bendix Corporation and the Boeing Company. The mobile laboratory concept was to have an operational capability of traversing a total distance of about 250 kilometers on the lunar surface and was to provide a shirtsleeve environment for two astronauts for a total stay-time of 14 days. During the mission, the astronauts would occasionally change into their pressure suits and life-support systems, exit the vehicle, and perform certain scientific experiments, collect samples, etc.

The contractor studies resulted in two different design concepts. The Bendix preliminary design resulted in a four-wheeled vehicle having two rather large portholes or windows in front providing the astronauts a view of the lunar surface while driving. A six-wheeled vehicle resulted from the Boeing preliminary design study. The two additional wheels provided what is essentially a trailer vehicle coupled to the forward section by means of a semi-flexible coupling or drawbar. Only one porthole or window was provided for the astronaut to use in driving the vehicle.

The study contracts were closely monitored by in-house personnel at MSFC, and during the preliminary study phase these personnel initiated a simulation program for driving both mobile laboratory concepts in order to properly evaluate the crew station designs.

After completion of the first year of study, there was a redirection of the design goals and criteria for lunar surface roving vehicles. Further study contracts were let to the same two contractors to provide preliminary designs of surface roving vehicles that are lighter in weight. These vehicles have no enclosure, life support being provided to a single astronaut by means of his portable life support system, i.e. back pack and pressure suit. These latter concepts are essentially scaled-down versions of the larger vehicles. Therefore, the simulation program developed for the larger vehicles still provided valid human factors engineering criteria for the crew stations.

II. GENERAL SYSTEM DESCRIPTION

The system to be described is designed to present to the driver a reasonably accurate simulation of the visual information he will receive and provide him with controls similar to the ones that will actually be available. Trade-offs have been made in some areas in order to save time and materials and to design experiments that provide reasonably difficult tasks for evaluation of the crew station designs.

The block diagram of Figure 1 outlines the overall system. Equations describing the motion of the surface roving vehicles were developed by Dr.H.Moore, staff member of the General Electric Computer Department.

Input commands to the vehicle equations come from manually operated controls through appropriate transducers and interface equipment. The output of the computer provides attitude and position information used to actuate panel instruments, to develop the visual display, and to provide a record of the driving experiment.

For maximum realism, the visual display utilized a three-dimensional terrain model, a closed-circuit television camera and projector system, and a viewing projection screen. Additional information used to provide attitude information was provided by a terrain sensor mechanism developed by Mr. Heinz F. Lahser of R-COMP-RS.

Full-scale cockpit enclosures were used to provide the required fields of view. These enclosures and the instrument panels were mounted on the general-purpose two-man cockpit system described in Section IV.

None of the subsystems mentioned are completely independent. Signals derived from the controls and terrain sensors must be transformed into computer commands. The computer program must in turn develop commands for the instruments, the visual display system, and the terrain sensor attitudes.

III. VISUAL DISPLAY

Visual simulation is provided by means of a U.S. Air Force SMK-23 visual simulator. It was originally used by the Air Force to provide visual pilot training in the most critical areas of flight - take-off and landing.

The SMK-23 (Figure 2) consists of a camera and model unit and a projector and screen which provide a subject with a 30°x 50° field-of-view of the three-dimensional terrain model.

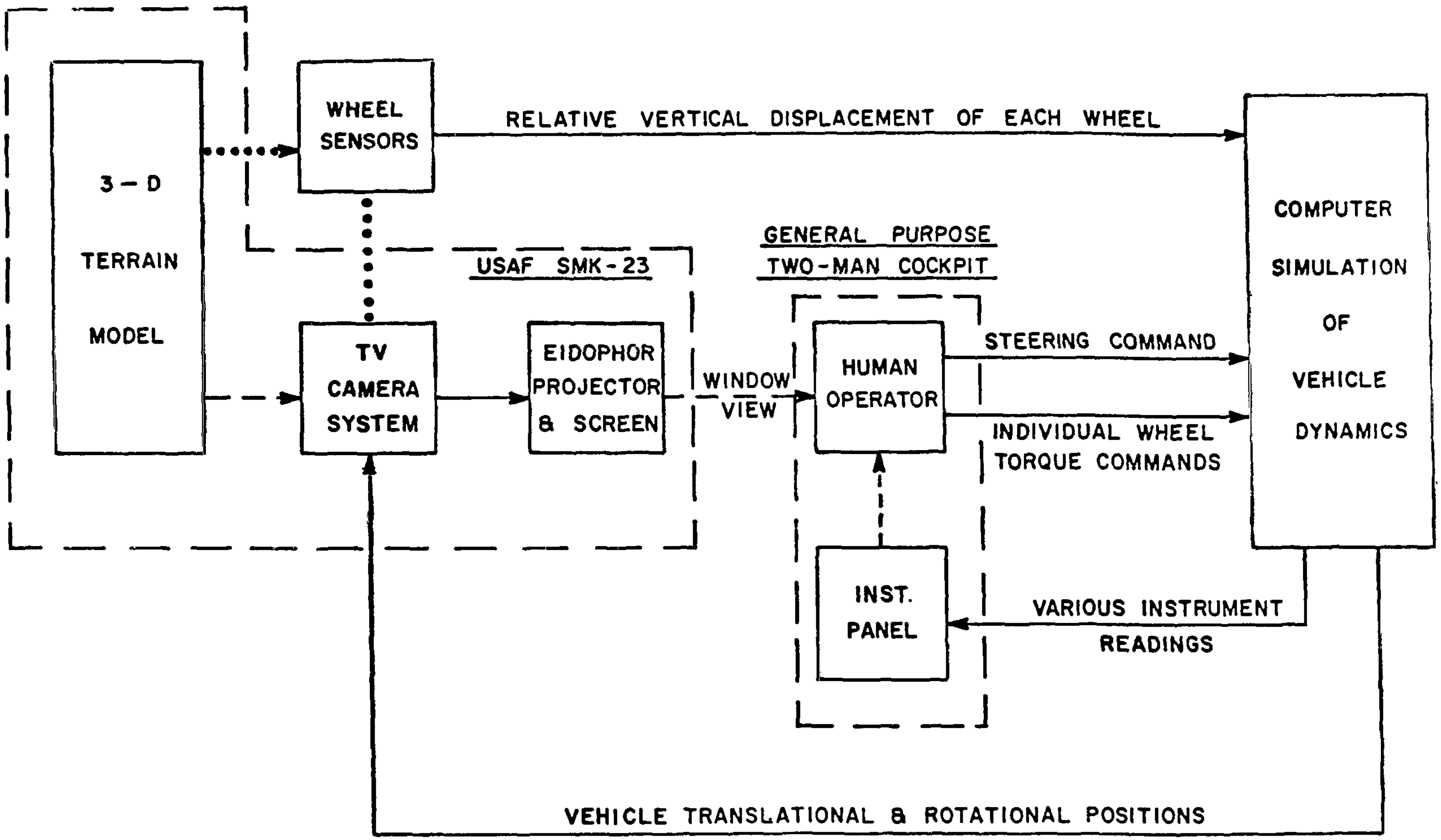

FIGURE 1. TYPICAL SIMULATOR APPLICATION FOR A LUNAR ROVING VEHICLE

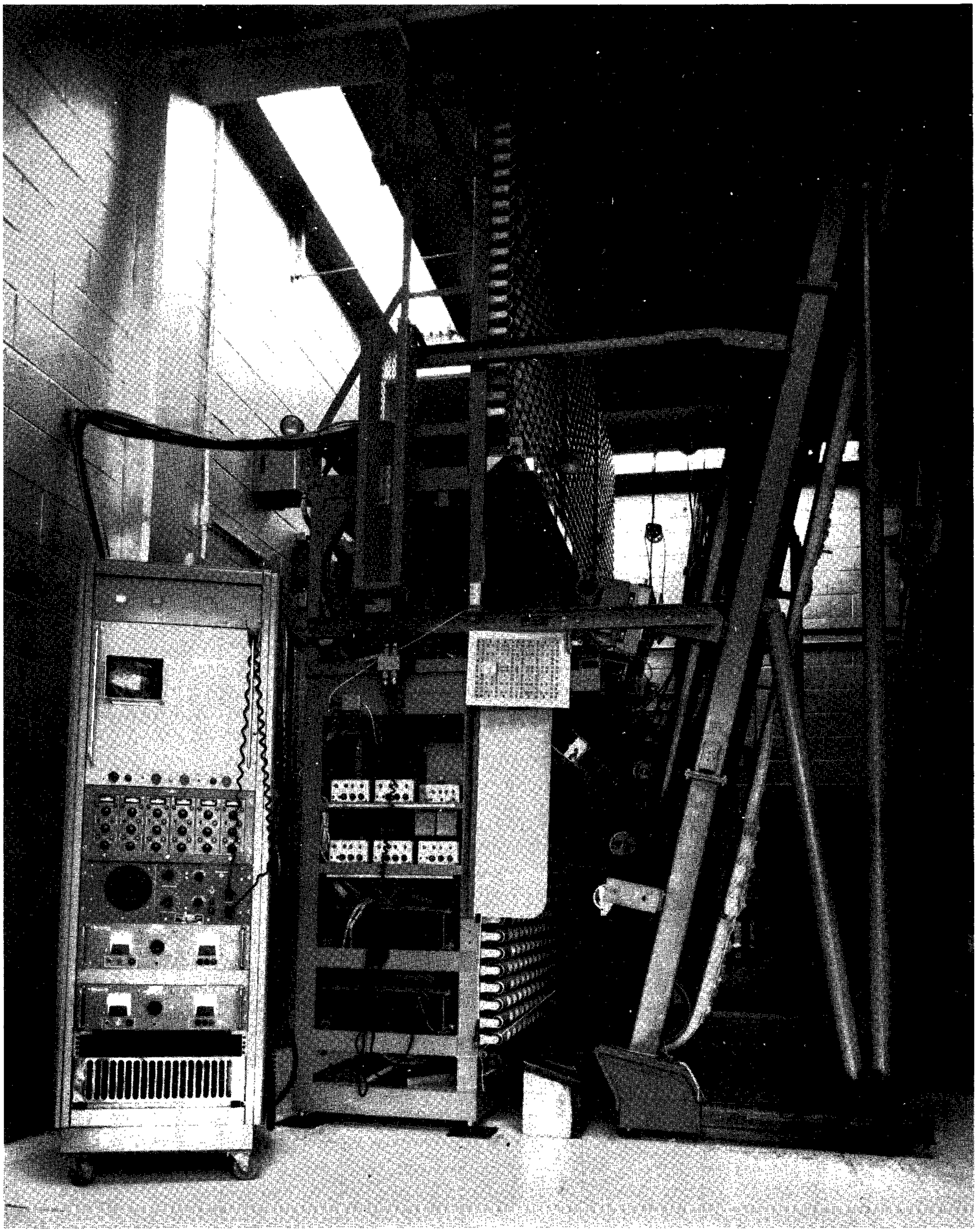

FIGURE 2. SMK-23 MODEL UNIT

The television camera scans the three-dimensional model with an optical pickup that provides pitch, roll, and yaw. Altitude and lateral motion is provided by moving the camera and pickup lens. Longitudinal motion is achieved by driving the terrain model. To allow for close approach of the optical pickup, the initial element in the optical chain is less than 2 millimeters in diameter. This permits lowering the entrance pupil to be within about 0.1 inch of the model.

The picture is provided by a Thompson-Houston 3-inch Image Orthicon camera and an Eidophor projector which uses the field sequential system of color reproduction. The Eidophor is a control layer projector which uses an electro-optical control of the light beam from an outside source to produce the picture rather than the electronic generation of projection light. The light output is limited mainly by the power of the light source; therefore it has the advantage of producing a larger picture with considerably sharper and brighter images. Color renditions are also very good in this system.

The terrain model is supported by belts. Overall dimensions of the model cannot exceed 12 feet wide by 27 feet long due to physical restraints of the model unit frame. The maximum separation of the camera and model is 8 inches.

The SMK-23 as delivered to MSFC and as used by the Air Force required several modifications so that it could be adapted for simulation of surface roving vehicles. These modifications affected the electronics, the optics, and the structure of the basic SMK-23 system.

The input electronics were converted to enable the system to receive d-c signals from the analog computers for positioning the six attitude and position servomechanisms. The heading synchro servo was converted to a position servo with a limitation of plus and minus 2 1/2 revolutions. Noise pickup in the camera was greatly reduced by providing additional shielding in the video amplifier.

The original bead lens optical pickup was replaced by a Librascope pickup. The picture resolution as a function of the angular field of view was greatly increased and made almost uniform throughout the entire field of view (Figures 3 and 4).

Structural supports were provided for mounting the Eidophor projector in the particular dimensions of our cockpit display room. Structural modifications were provided to the framework housing the model. In order to avoid imparting extraneous vertical motions to the terrain sensors, the model frame was tilted 12 degrees from the vertical and provided with backup plates. The camera unit was then tilted the corresponding 12 degrees to keep the optical axis perpendicular to the terrain model (Figure 5).

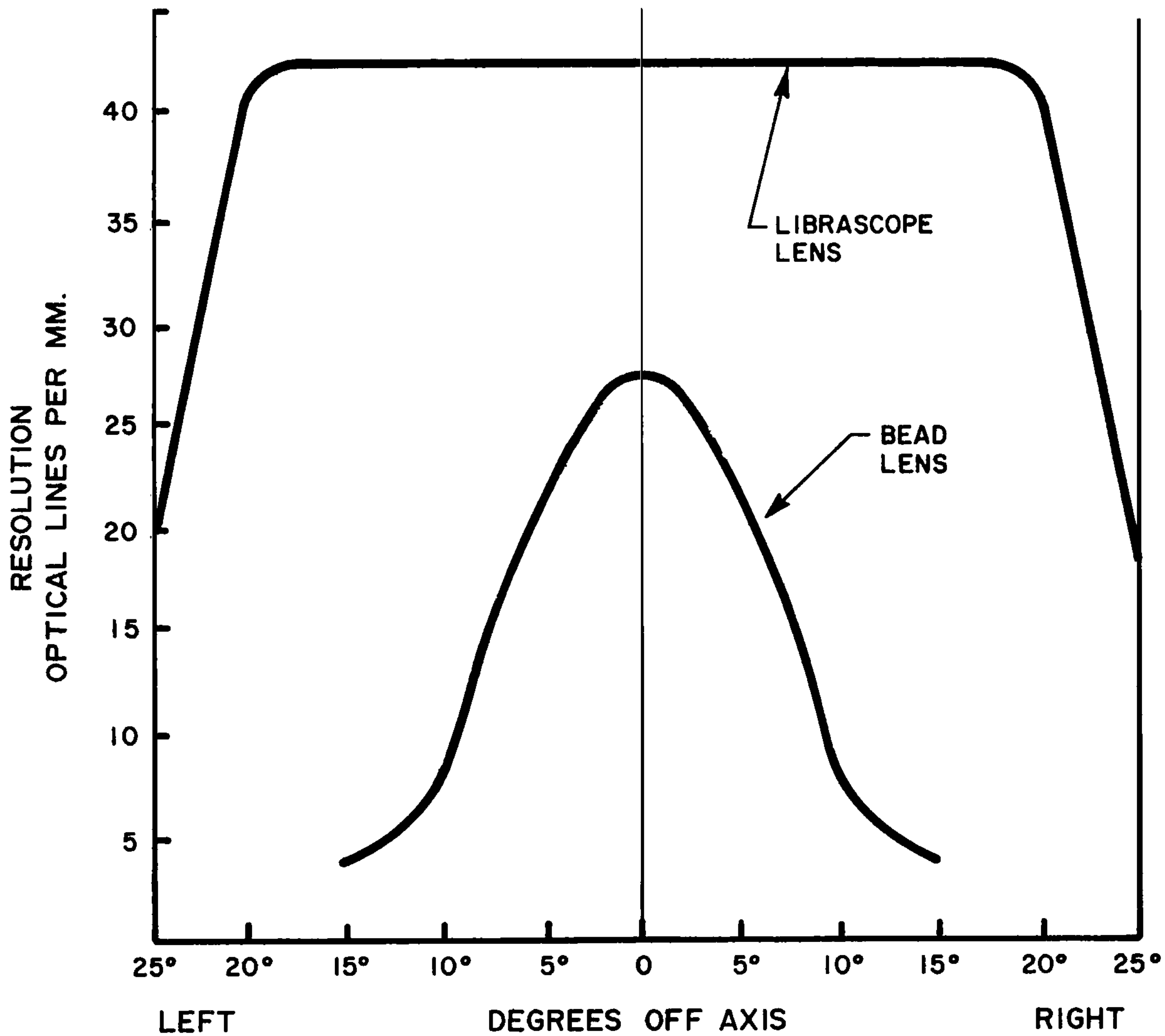

FIGURE 3. LIBRASCOPE VERSUS BEADLENS RESOLUTION DIAGRAM (TV AND LENS)

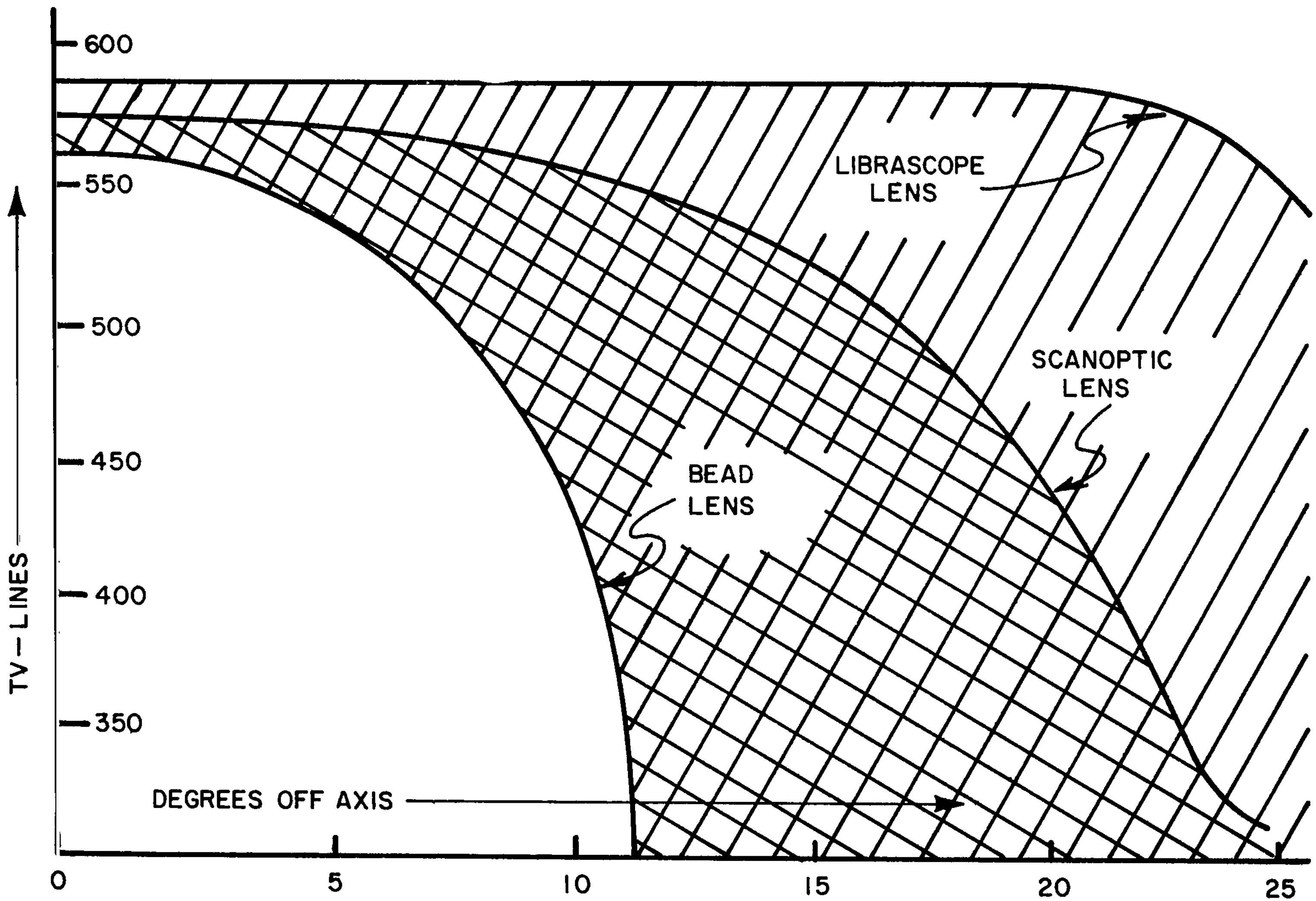

FIGURE 4. SMK-23 TOTAL SYSTEMS RESOLUTION

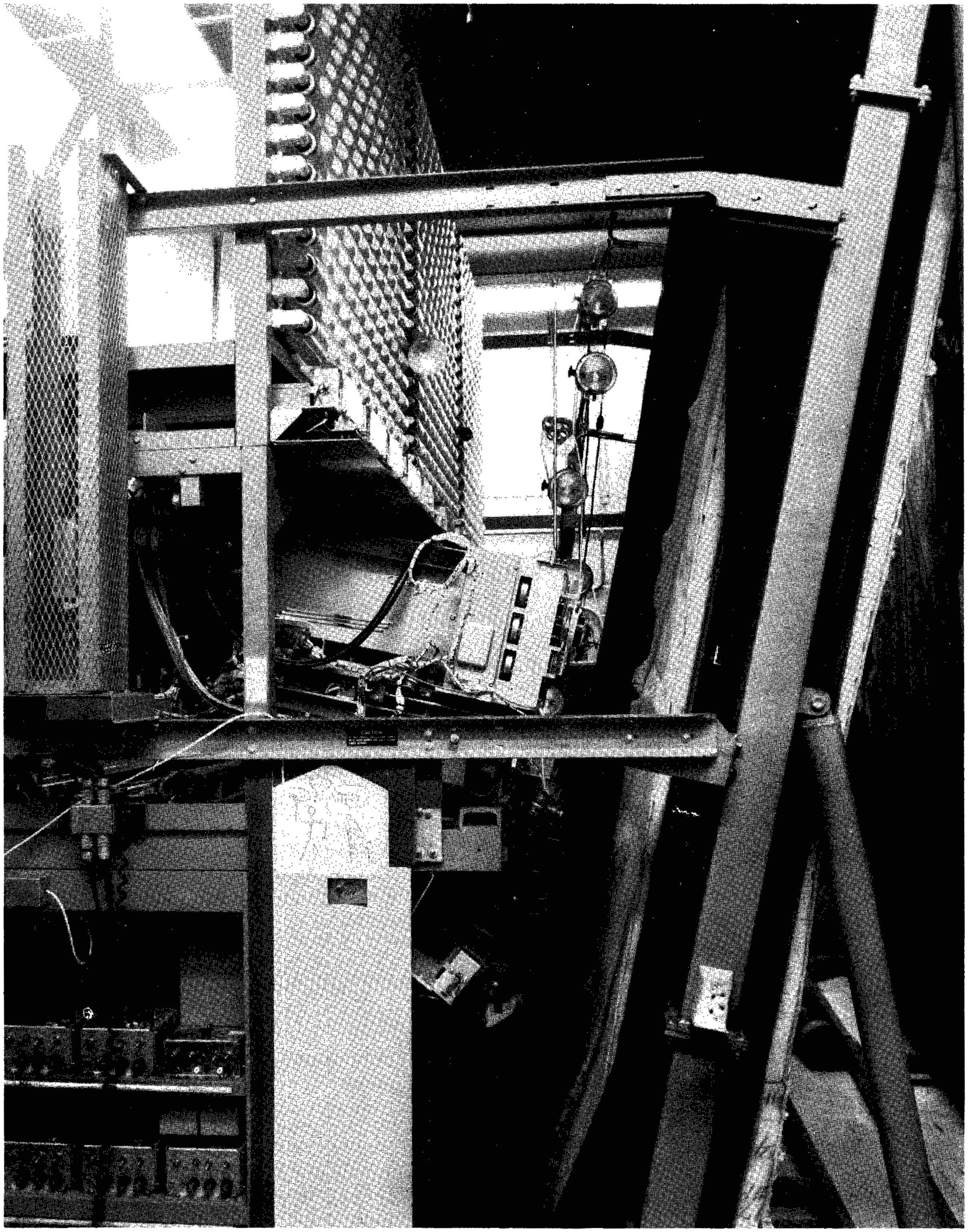

FIGURE 5. SMK-23 MODEL UNIT (CAMERA)

Since the moon was believed to be essentially colorless, it was decided to operate the camera and projector as a black and white system. Several advantages resulted from this decision. By removing the color wheel from the camera, the gain in the light reaching the image orthicon was sufficient to permit operation of the simulator with much less light on the model. It was no longer necessary to flood the terrain model with a solid array (24 kw) of lighting, but it was possible to use parallel lighting from the side so that shadows could be cast. Also, it was possible to reduce the aperture of the optics from .038 inch to .025 inch, which greatly increased the depth of field. It was found that any further reduction in the aperture resulted in a noticeable loss of resolution due to diffraction limiting.

A blue filter was attached to the projector lens to filter out the large amount of red light produced by the Xenon lamp, giving the picture a light blue tint. This filter also shifted the frequency of the reflected light and other optical noise to a portion of the spectrum less noticeable to the eye.

The scale of the terrain model was finally fixed at 1 to 150. This value was determined by the size of the terrain sensors used to correlate the visual picture with the dynamics of the simulated vehicle as it would react to the terrain surface features.

The resultant capabilities and limitations of the simulator are as follows:

A. Attitude

	Roll	Pitch	Heading
Position (degrees)	$\pm$ 60	$\pm$ 25	$\pm$ 900
Rate (deg/sec)	172	64	115
Acceleration (deg/sec)	500	100	500
Accuracy (degrees)	$\pm$1	$\pm$1	$\pm$1

B. Optical

Minimum Viewing Distance	20 feet (scaled)
Maximum Viewing Distance	2, 000 feet (scaled)
Minimum Object Size	6 inches (scaled)
Brightness of Projected Picture	7 foot-lamberts
Picture Resolution	6-10 arc minutes

The picture is provided by a 441 scan-line system. The color rendition is eight tones per color.

The terrain model does not have the capability of representing dust clouds or showing the tracks of the vehicle path.

IV. CREW STATION AND INTERFACE CONTROL CONSOLE

The earlier development of the general-purpose two-man cockpit and the general purpose interface console were greatly beneficial to the operation of the surface roving vehicle studies. Prior work with fixed-base simulators demonstrated a number of difficulties in rearranging instrument panels, controls, and seating arrangements and in interconnecting the instruments and controls with computer programs.

The general-purpose two-man cockpit (Figure 6) was designed by the Boeing Aerospace Division in Seattle, Washington under contract to MSFC. The cockpit, designed for maximum flexibility, features a modular concept by which the major items of the crew station can be incorporated in a building-block fashion to represent a variety of vehicle designs.

The enclosure is not rigidly attached to the cockpit floor but is mounted on rollers. Thus, it can be lifted off and a different enclosure, representing a different vehicle, can easily be installed.

The instrument panels are not attached to the enclosure, but rather are mounted to the floor. Quick-disconnect plugs are located just under the floor to provide connections between the instrument panels and the interface console.

The enclosures and instrument panels used for the surface roving vehicle studies are shown in Figures 7-10. The panels and enclosure for the Boeing vehicle concept were built by the Boeing Aerospace Division in Seattle, Washington. The panels and enclosure for the Bendix vehicle concept were built by Lockheed Missiles and Space Company in Sunnyvale, California.

The interface console (Figure 11) features a removable patch panel and contains power supplies, bridge limiters, control relays, simulation monitoring instruments, closed-circuit television monitors, and servos for driving synchro-type instruments. The removable patch panel is of utmost importance to the overall modular concept. All interconnections between the crew station and the general-purpose analog computers are made on this patch panel.

The flexibility offered by the modular design concept allows a complete change-over between vehicle simulations in a matter of a few hours. To change simulation programs requires changing computer and interface console patchboards, installation of a different instrument panel, and placing a different enclosure on the roller base.

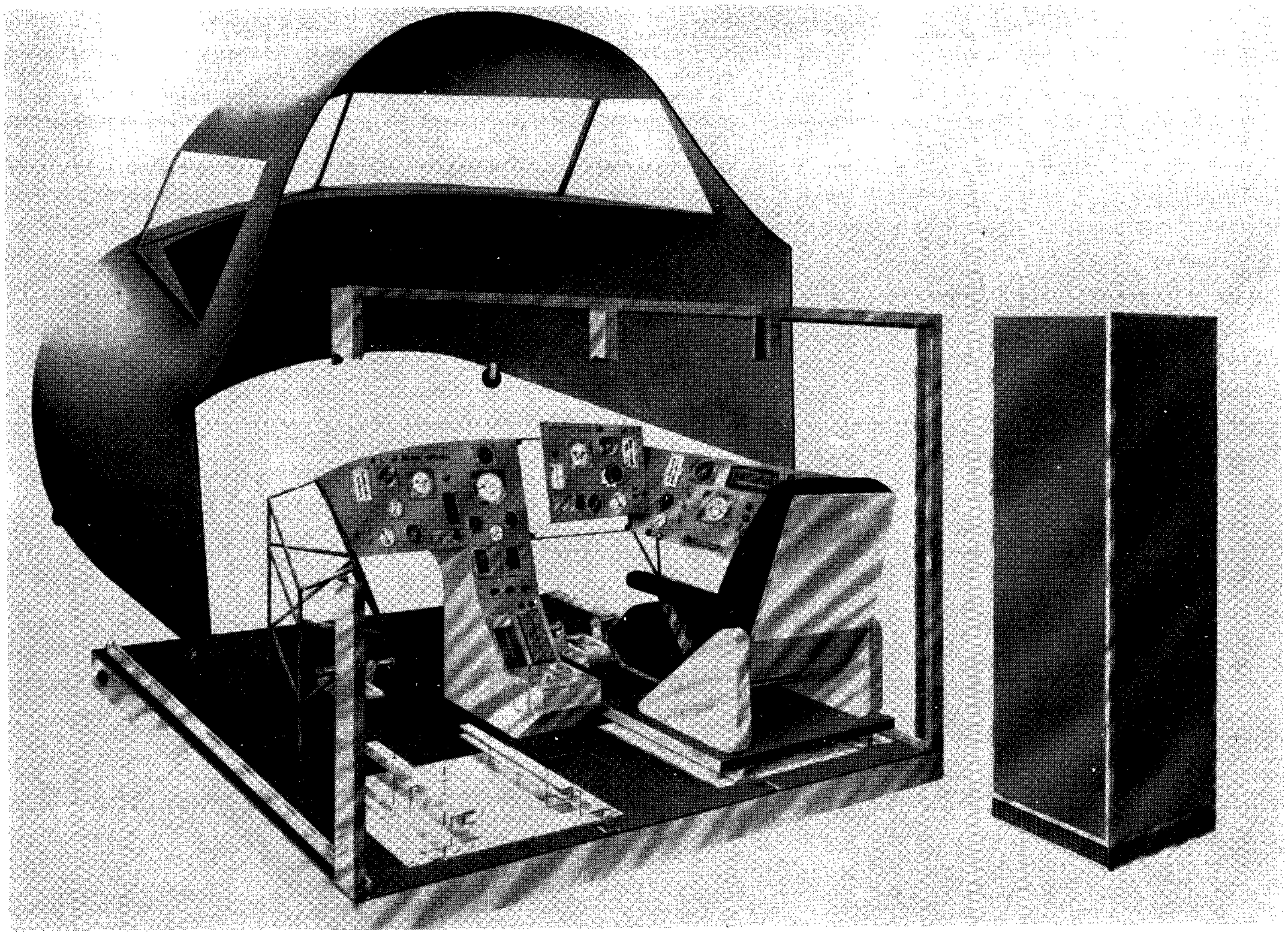

FIGURE 6. GENERAL PURPOSE TWO-MAN SIMULATOR COCKPIT

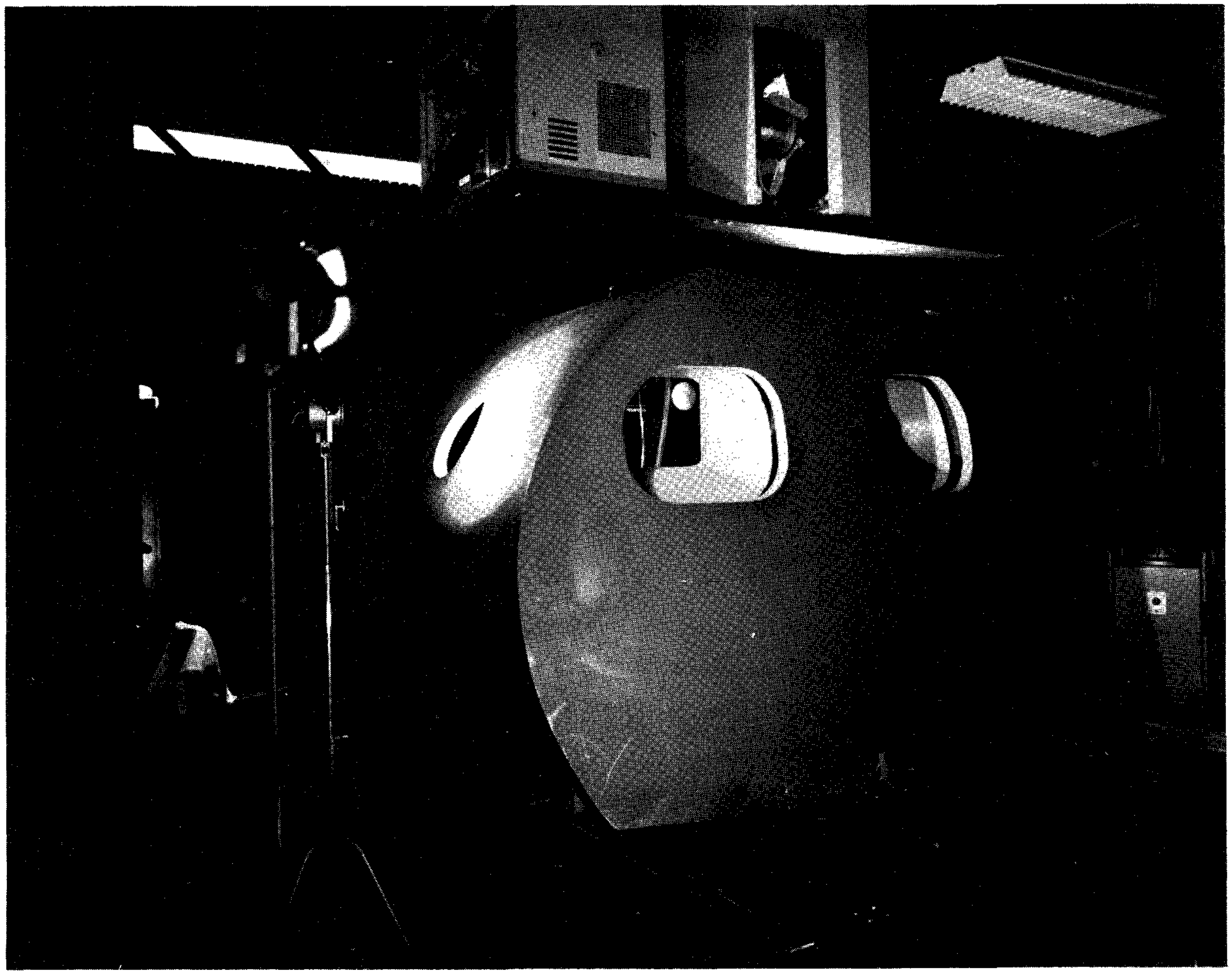

FIGURE 7. BENDIX MOLAB ENCLOSURE OF TWO-MAN SIMULATOR COCKPIT

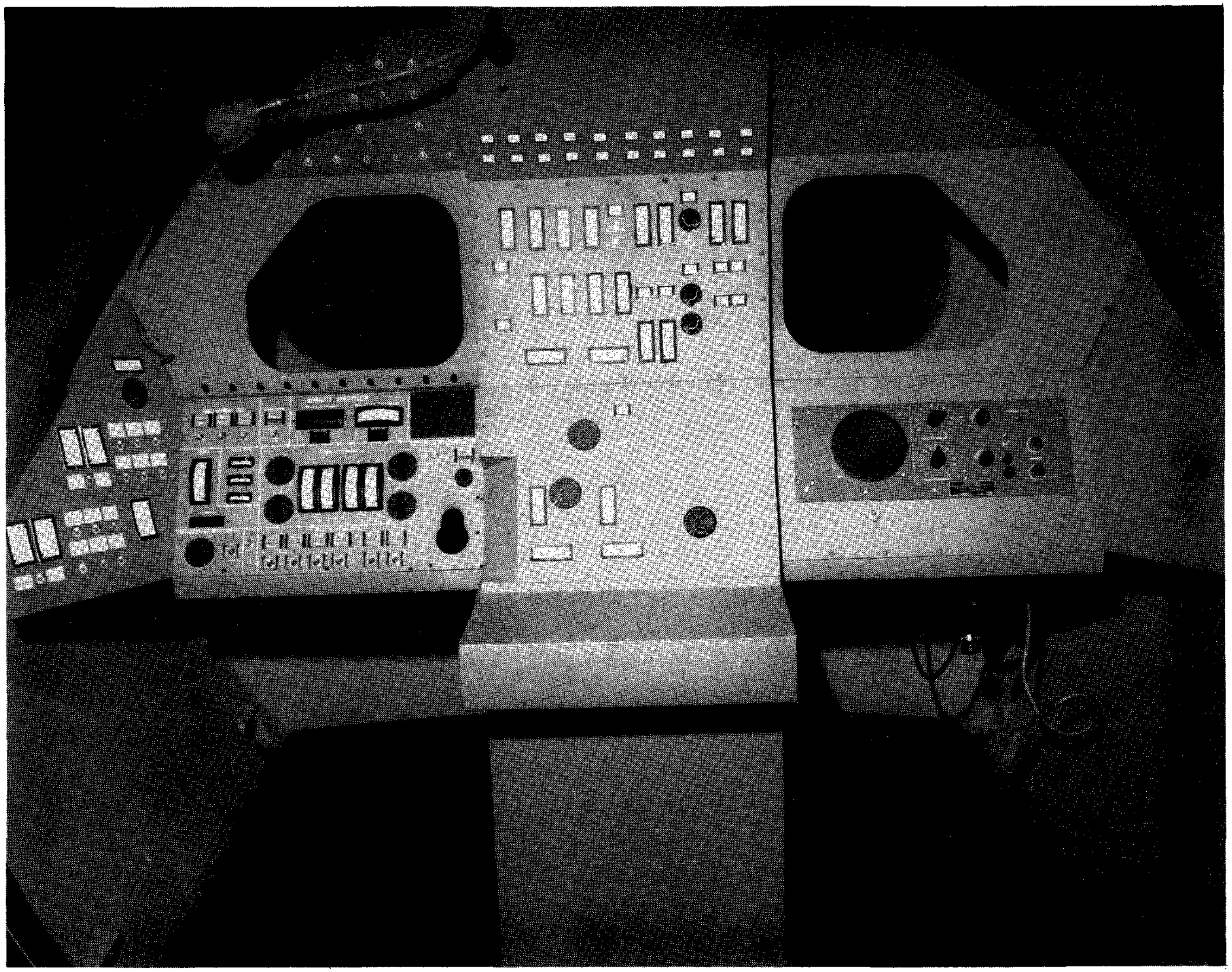

FIGURE 8. BENDIX INSTRUMENT PANEL

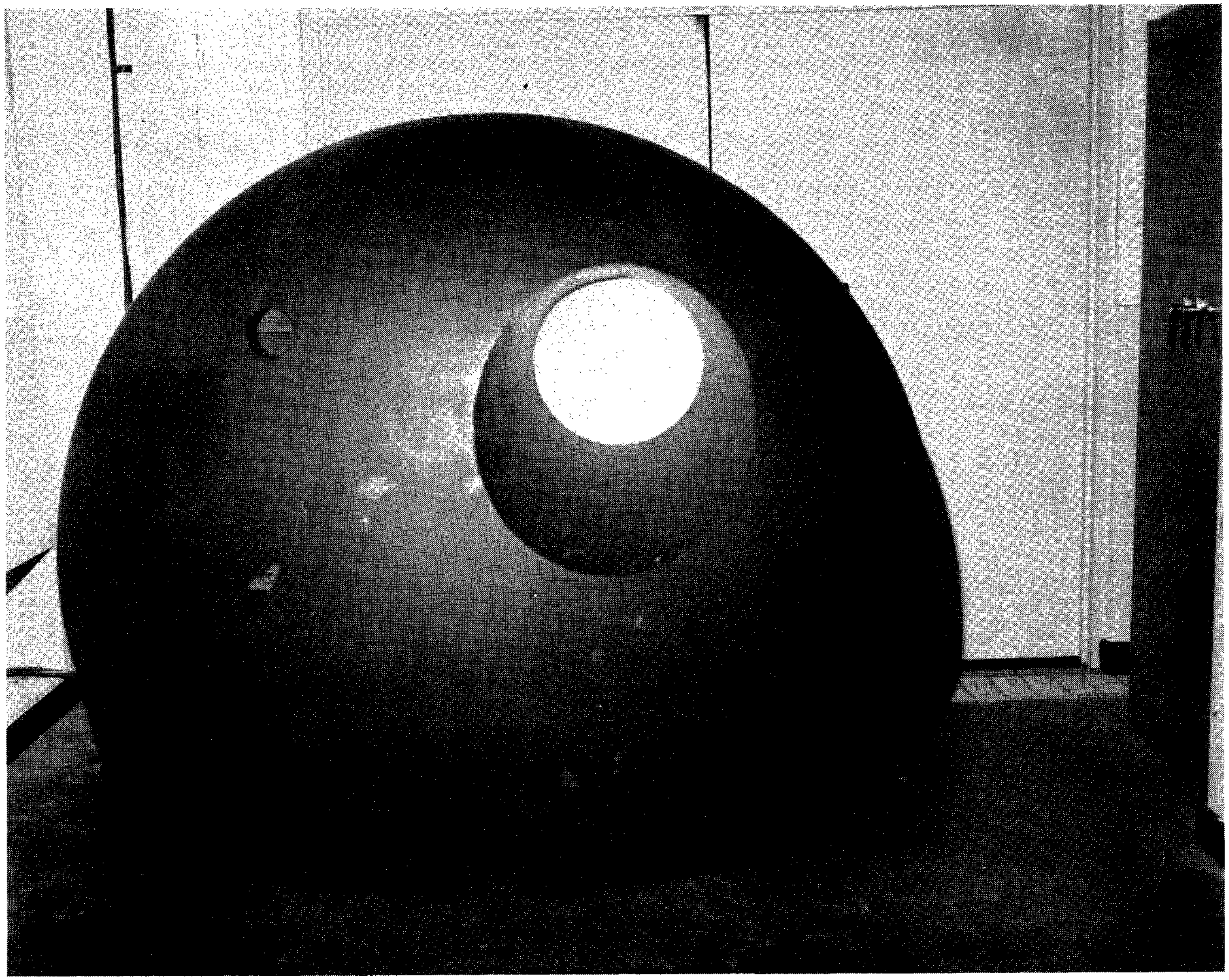

FIGURE 9. BOEING ENCLOSURE OF THE TWO-MAN SIMULATOR COCKPIT

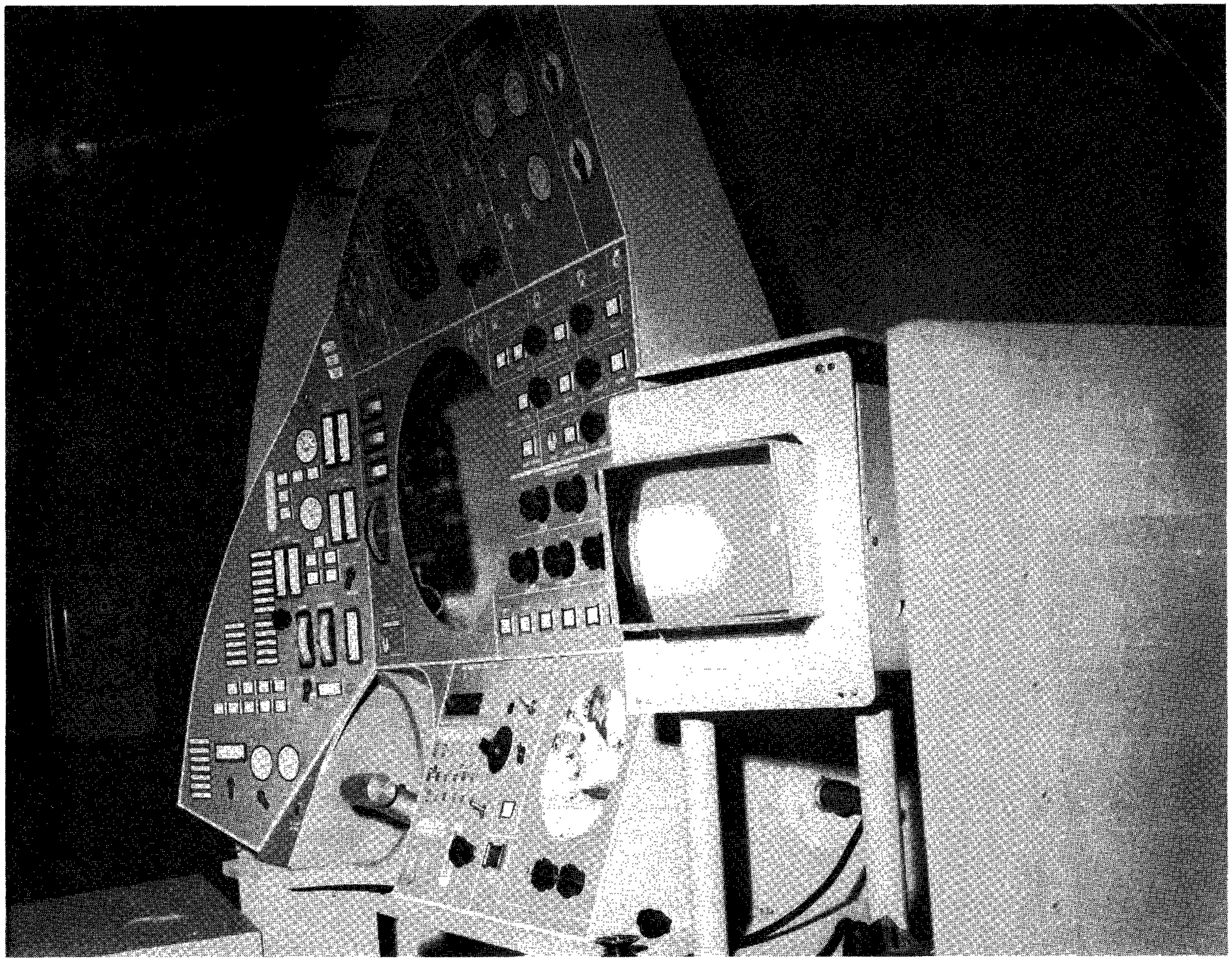

FIGURE 10. BOEING INSTRUMENT PANEL

FIGURE 11. INTERFACE CONSOLE

V. TERRAIN SENSOR

The task of developing a terrain sensor which could be mounted in the very limited area around the initial element of the optical pickup, provide the proper eye point, and yet maintain the required accuracy and the capability of negotiating the terrain model, led to numerous efforts. The first efforts were aimed at selection of the type and shape of simulated wheels to be used. For this purpose, a linear transformer (type "Crescent East" 1.0-3K-9E, 400 cycle) was used to test the various designs. The scale size for the wheels was varied from 100:1 to 300:1. The ratio to be used in the final design was not determined at this time. The wheels were mounted on the rod of the linear transformer and spring-loaded with a pressure of 30 grams against a medium rough rubber plate simulating the lunar surface.

The various design attempts, beginning with the linear transformer and moving clockwise, are shown in Figure 12. The use of a wheel was discarded, because in case of computer malfunction or manually attempting to move the vehicle laterally, the wheel would not roll, it blocked, and consequently bent the rod and damaged the linear transformer. A cylindrical shaft with a polished hemisphere on the end was attempted, but too much friction between the shaft and the map occurred. A free-rolling device, operating on the same principle as a ballpoint pen was then introduced. Troubles occurred with this device in maintaining a proper ratio between wheel diameter and tread size. Finally, a brass holder with a free rolling steelball was constructed which took into account the average dimensions of the diameter and width of the wheel. With this type of wheel the best results were obtained.

Figure 13 shows the first five versions which were developed and tested.

#1: Linear transformer with mounted small wheel, two springs, spring pressure adjusted. Four of these 4 inch by 1/2 inch units are required to simulate the four wheels. This version proved to be too large in dimension, the rod was too flexible and of very poor repeatability.

#2: This is the NASA mockup with a ratio 300:1. Four wheels (4 rolling balls) are mounted on a metal ring. In the center of this ring is a copper-beryllium cross with one 125Ω straingauge attached to each arm. The vehicle pivots around the center point of this cross. Any bending of the crossarms results in stretching or compressing of the straingauges. Signals are then sent out over a bridge circuit and a straingauge amplifier to a computer which, in turn, operates the servos. This design has not given satisfactory wheel positioning, due to cross-coupling between the sensors.

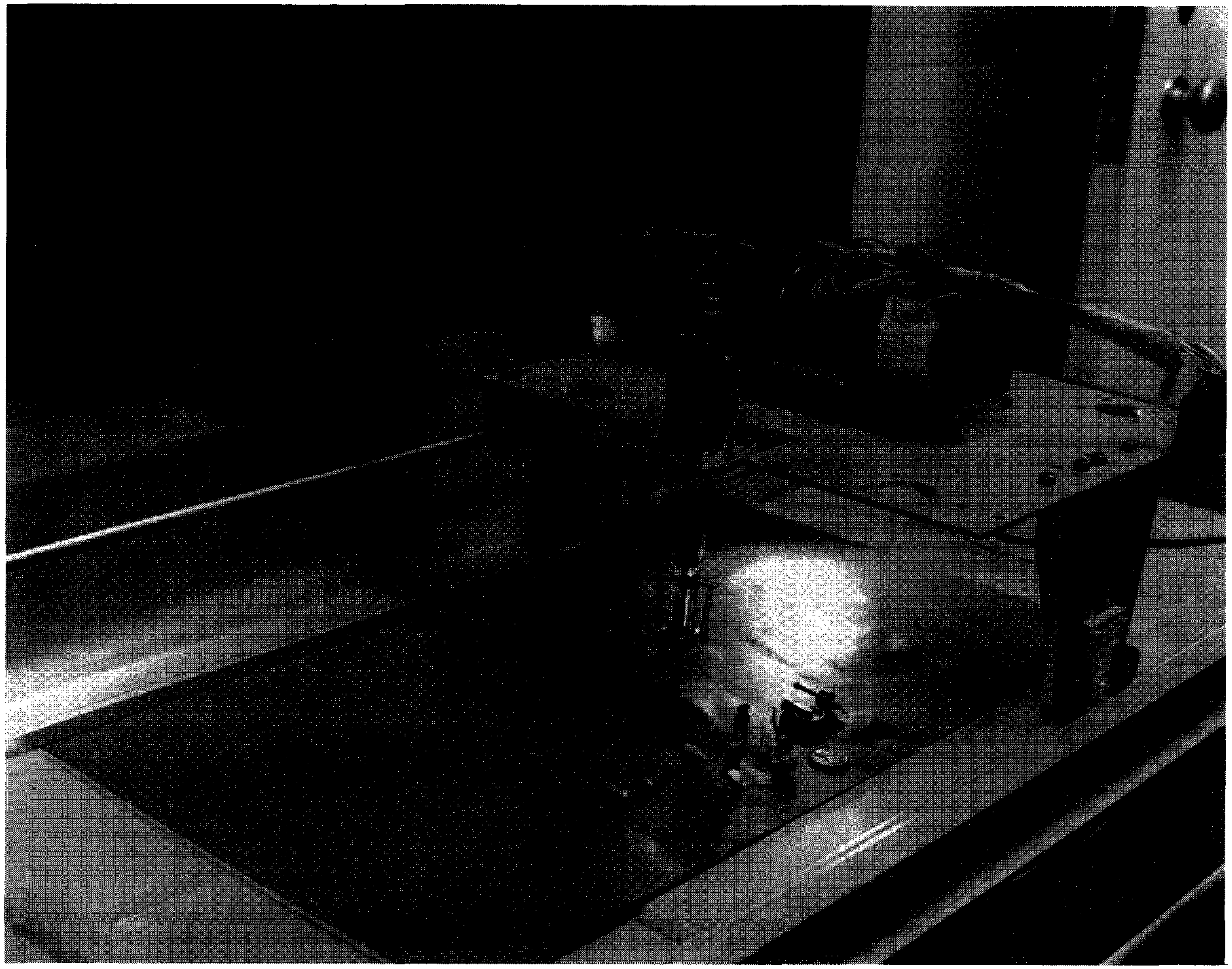

FIGURE 12. FIRST SENSOR DESIGNS AND TEST APPARATUS

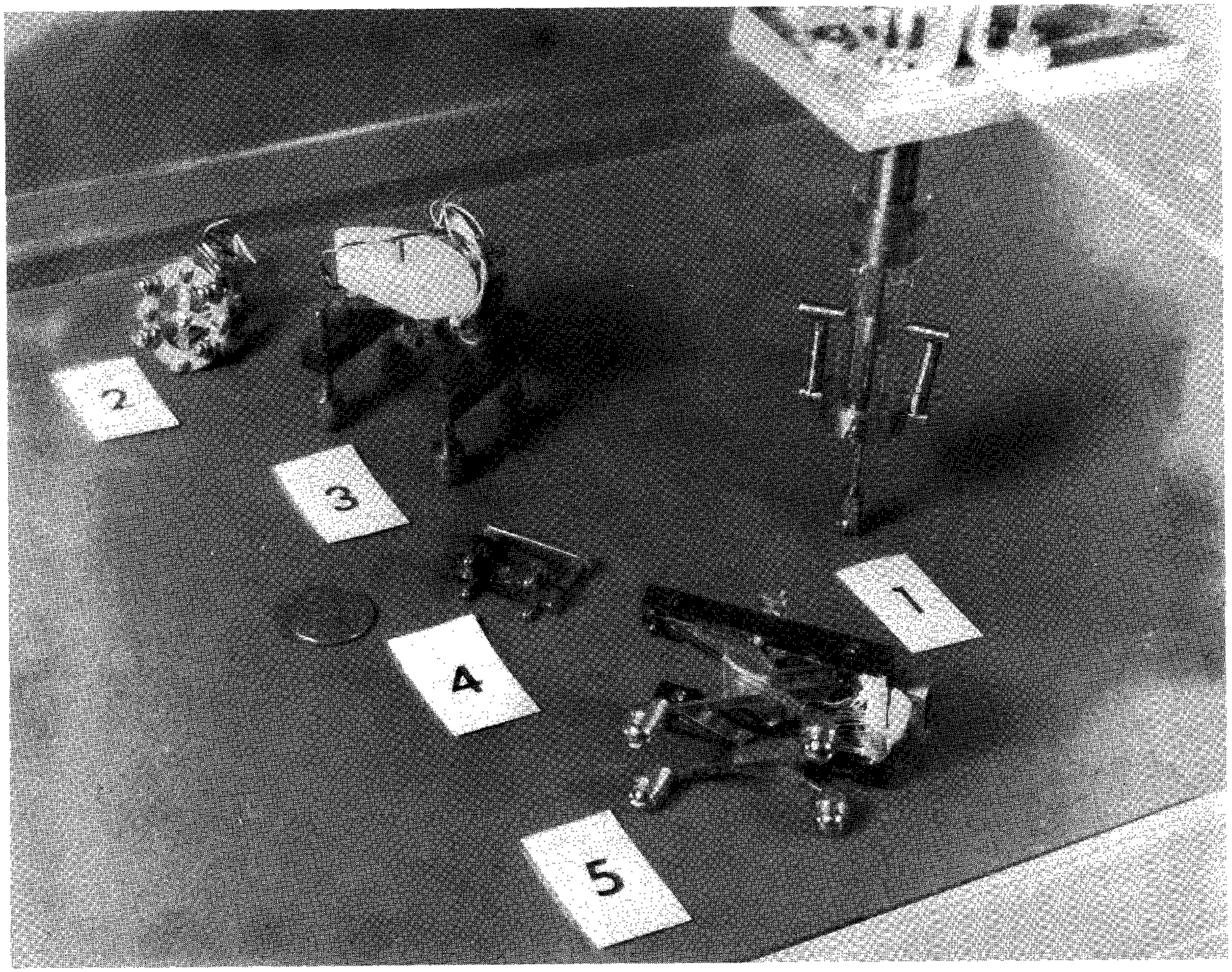

FIGURE 13. VARIOUS SENSOR DESIGNS

#3: This shows the NASA mockup with a ratio 100:1 as pistontype vehicle. In this design an open-front U-shaped frame with four separate copper-beryllium springs and one 125Ω straingauge on each spring was used. Each spring applies a pressure of 20 grams to the top of each piston. Any change in elevation puts the piston in a different position and bends the spring, thus changing the resistance of the straingauges. Test runs of this device in connection with the servo-driven platform were satisfactory.

#4: This shows the same vehicle but with a ratio 300:1. No tests were conducted, because a ratio of 150:1 was finally determined.

All these preliminary designs and subsequent tests were made to develop the most efficient system for sensing a terrain surface. The main difficulty in mounting the sensor devices in front of the optic was the very limited area available for a vehicle with a ratio of 150:1. Average measurements from the map surface were determined to be:

1) 5/8 inch distance to pitch axis mounting; 5/8 inch diameter
2) 1 1/8 inch distance to heading ring; 1 1/4 inch diameter
3) 1 7/8 inch distance to gearbox TV camera.

In this very limited space a holder or mounting of the sensor device had to be built without blocking the view in the driving direction.

Several weeks after completing the first test series, the blueprints of the Bendix Molab were obtained and the order to build a simulated Bendix vehicle with a ratio of 150:1 was received. The distance between front and rear axis of this vehicle was more than twice the distance of the NASA mockup and the eye point was located close behind the front axis. The vehicle had to be capable to negotiate a 25° to 30° slope; this required a piston length twice than that used in the NASA mockup, and consequently left no room between surface map and optics. We therefore had to change to scissor-type sensor arms (#5). Test runs with this vehicle were very satisfactory. Using straingauges proved to be the only acceptable method for mounting the sensing devices.

The first SMK-23 simulator was received in July 1965 and development of a standard mounting device and framework for all vehicle types proceeded immediately. A three-point springloaded steelball snap-on device mounted on the rotating part of the optics was developed, and is shown in Figure 14.

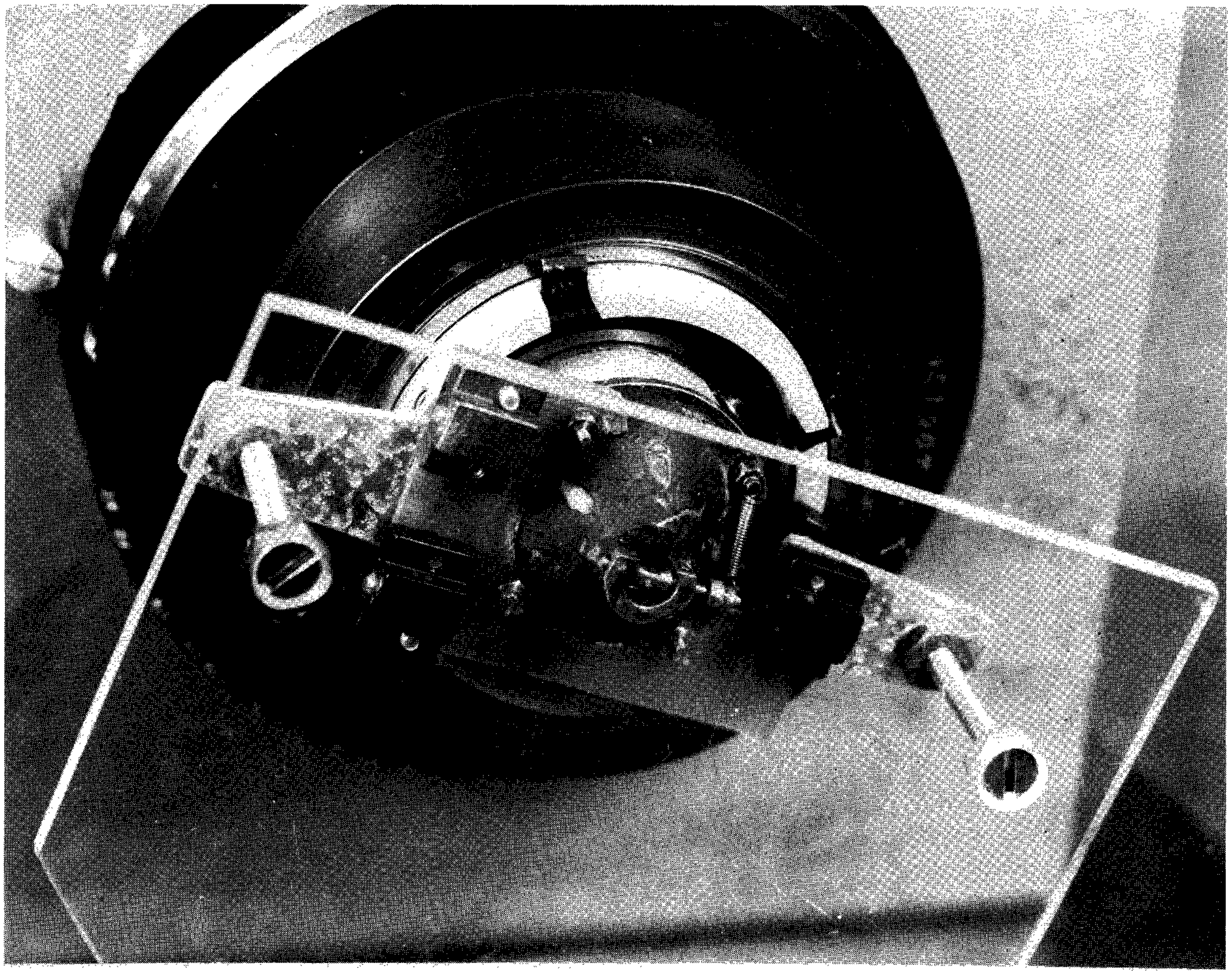

FIGURE 14. SENSOR MOUNTING DEVICE

The plexiglass plate was installed only to show the sensors in their normal operating position.

A standard U-shaped aluminium frame usable for all vehicle types was constructed. The sensor arms carrying the wheels (steelballs) were manufactured from 1/32 inch diameter Copper-Beryllium wire. This wire is strong enough to withstand 10 to 15 grams pressure without bending, but would bend or break in case of heavy impacts (Figure 15).

Some difficulties occurred after two weeks running time -- the steelballs would not move in the holders and their surface showed heavy corrosion. The latter was caused by the peroxide and sulphur which is contained, in large amounts, in the foam material and Latex used in the terrain model. After replacing the steelballs with stainless steel or Teflon balls, this trouble was eliminated.

Figure 16 shows the crash sensor arm positioned between the wheels. In case of blockage, each sensor arm will eject the frame from the three-point holder (approximately 200 grams pressure) and operate automatically the crash sensor which is mounted on each vehicle. The crash sensor is a small micro-switch which in case of impact operates a safety relay to pull the camera back from the map and also freezes all other servos. A few grams touch from any direction will activate the crash sensor. Its arm is positioned between optics and map, between the wheels, at approximately 3/8 inch distance from the map. The crash sensor is a very useful safety device to prefent damage of the pitch mirror and optics in case of computer malfunction, rough driving through craters, or hitting obstacles.

Figure 17 shows the last design of the Bendix (number 1) and Boeing (number 2) simulated vehicles. Number 3 shows a Copper-Beryllium spring, on which the straingauge is mounted, a complete ball holder device with Teflon ball, an insert of a ball bearing (1/2 inch) used for the rear wheels on vehicles to negotiate slopes of over 30 degrees, and a crash sensor.

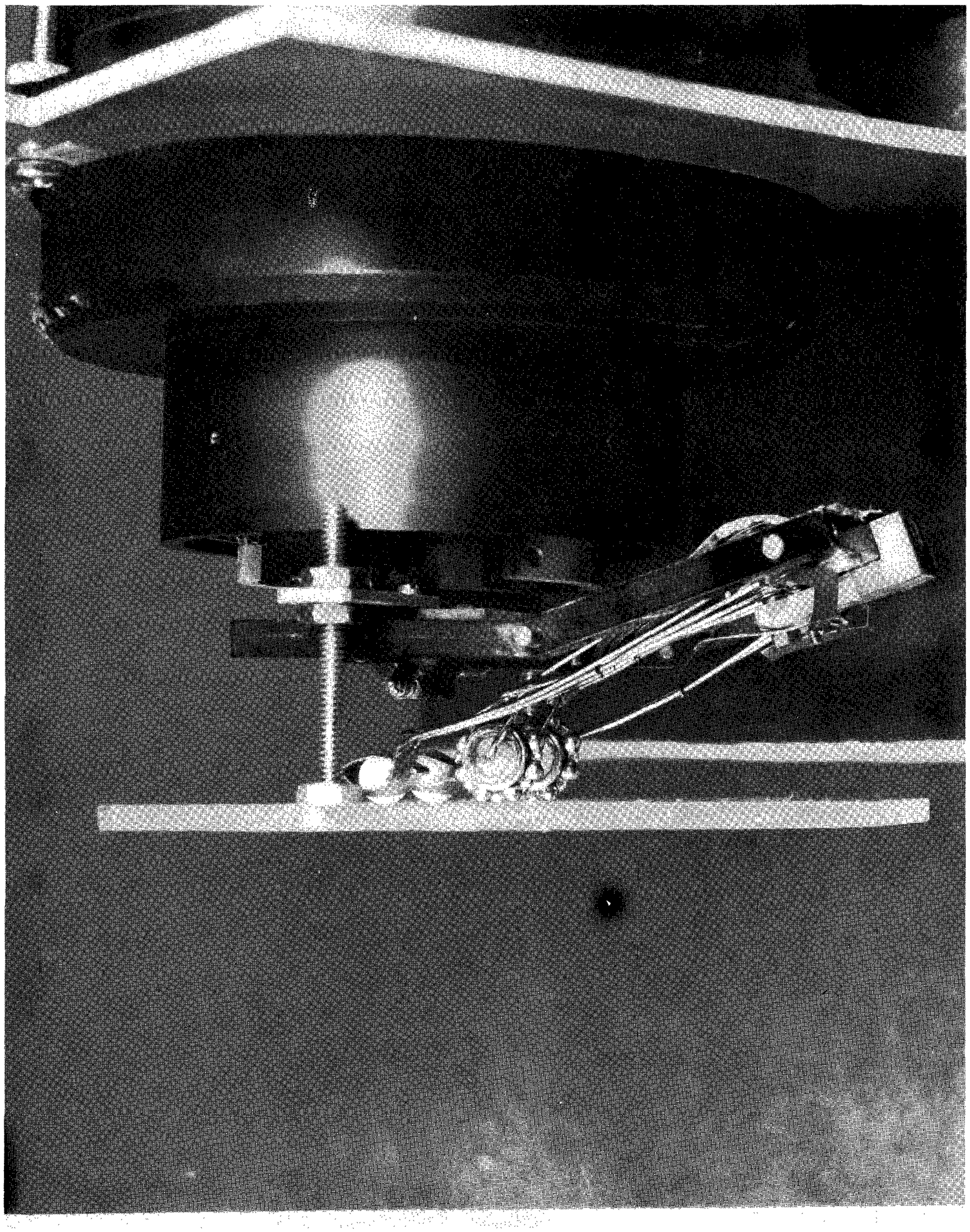

FIGURE 15. SENSOR DEVICE - SIDE VIEW

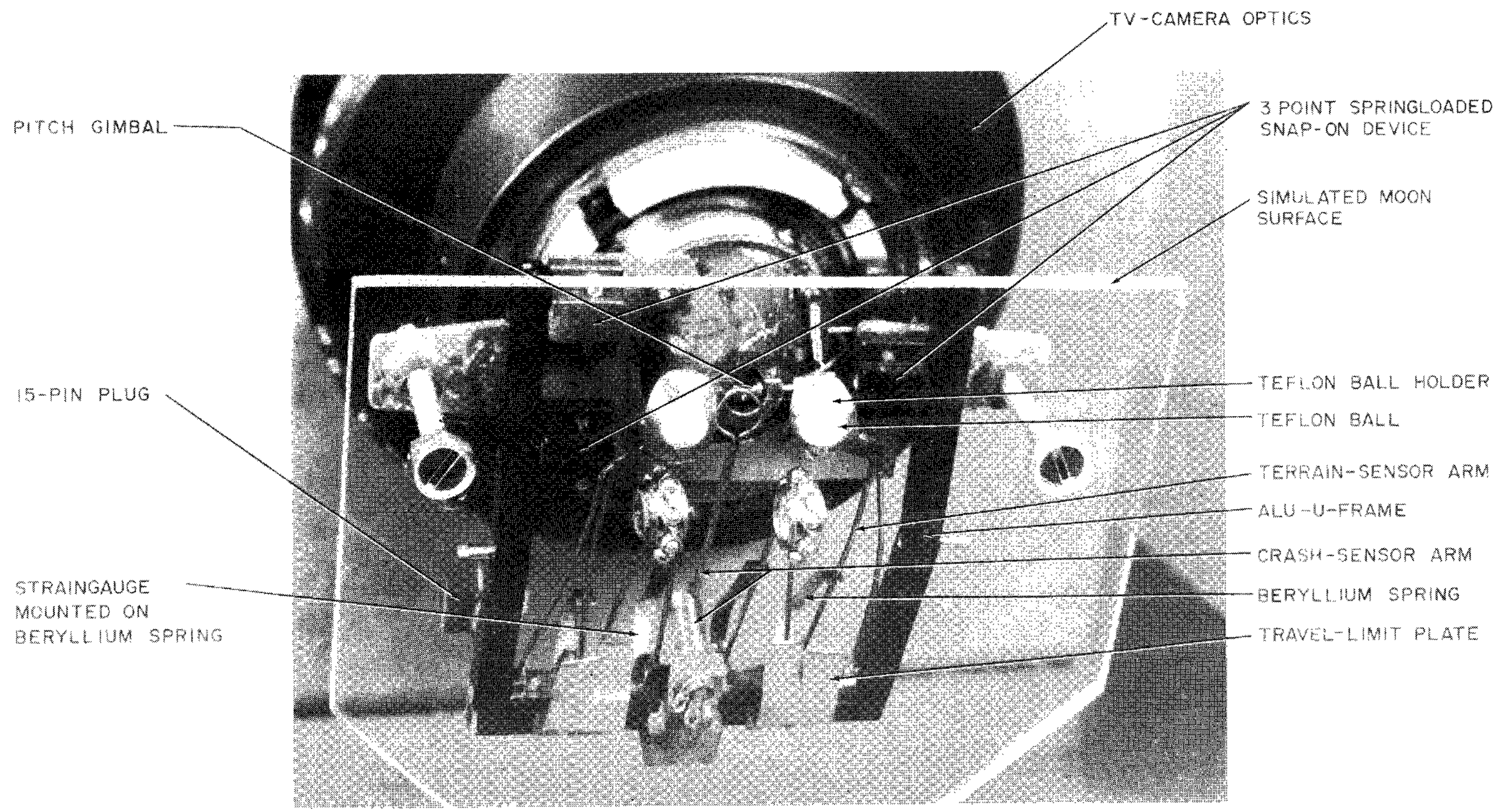

FIGURE 16. SENSOR DEVICE - BOTTOM VIEW

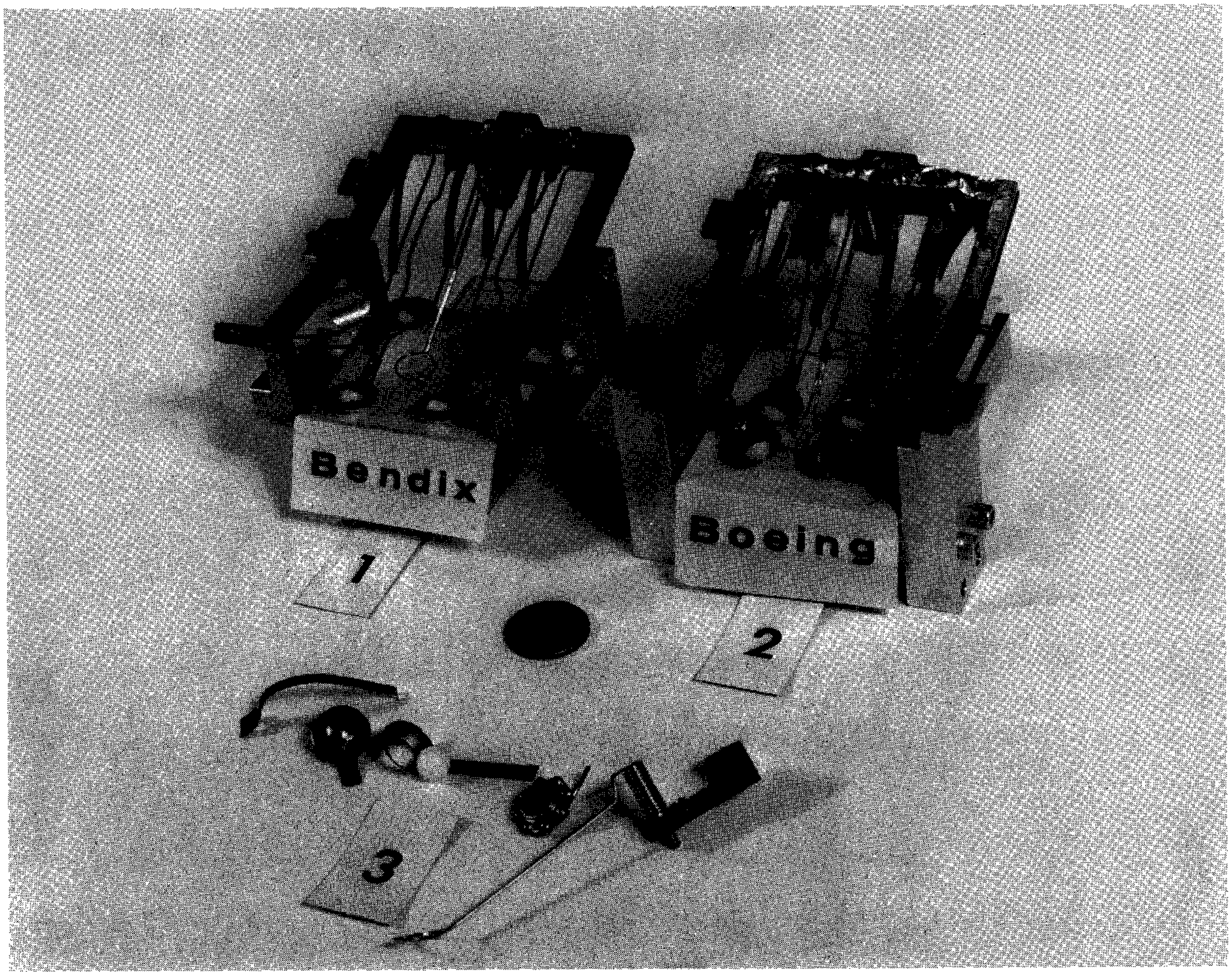

FIGURE 17. FINAL SENSOR DESIGN

VI. COMPUTER PROGRAM

The mathematical models for the two surface roving vehicles were based on prior MSFC studies of suspension systems and on reports prepared by the two contractors at the end of the first year study effort. The resulting computer programs were tested extensively to assure the validity and stability of both the mathematical model and the computer program.

The computer program for the Bendix vehicle concept simulated the four wheel vehicle having four wheel drive and front wheel Ackerman steering. All wheels were assumed to be flexible and able to move in a vertical plane with respect to the vehicle. The program included wheel slippage and the loss of individual wheel torque contribution whenever the wheel was off the ground.

The computer program for the Boeing vehicle concept simulated the six wheel vehicle. This vehicle had six wheel drive, Ackerman steering control on the two front wheels, and articulated steering about a pivot point at the junction of the two wheel aft unit and the elastic drawbar frame which connected the two units. Since the terrain sensors have only four contact points, terrain information for the trailer wheels was generated by a velocity dependent time delay program.

Figures 18 through 25 show the computer program for the two simulations. The computers utilized are listed below:

1)	EAI 231-R	Analog Computer
2)	EAI 221-R	Analog Computer
3)	ADI 9500	Analog Computer
4)	DR-20	Digital Resolver
5)	DDP-116	Digital Computer
6)	PDP-8	Digital Computer.

Simulation of the Bendix concept utilized items 1, 2, and 4 in the preceding list. The Boeing concept, with the trailer and coupling, required the addition of items 3,5, and 6.

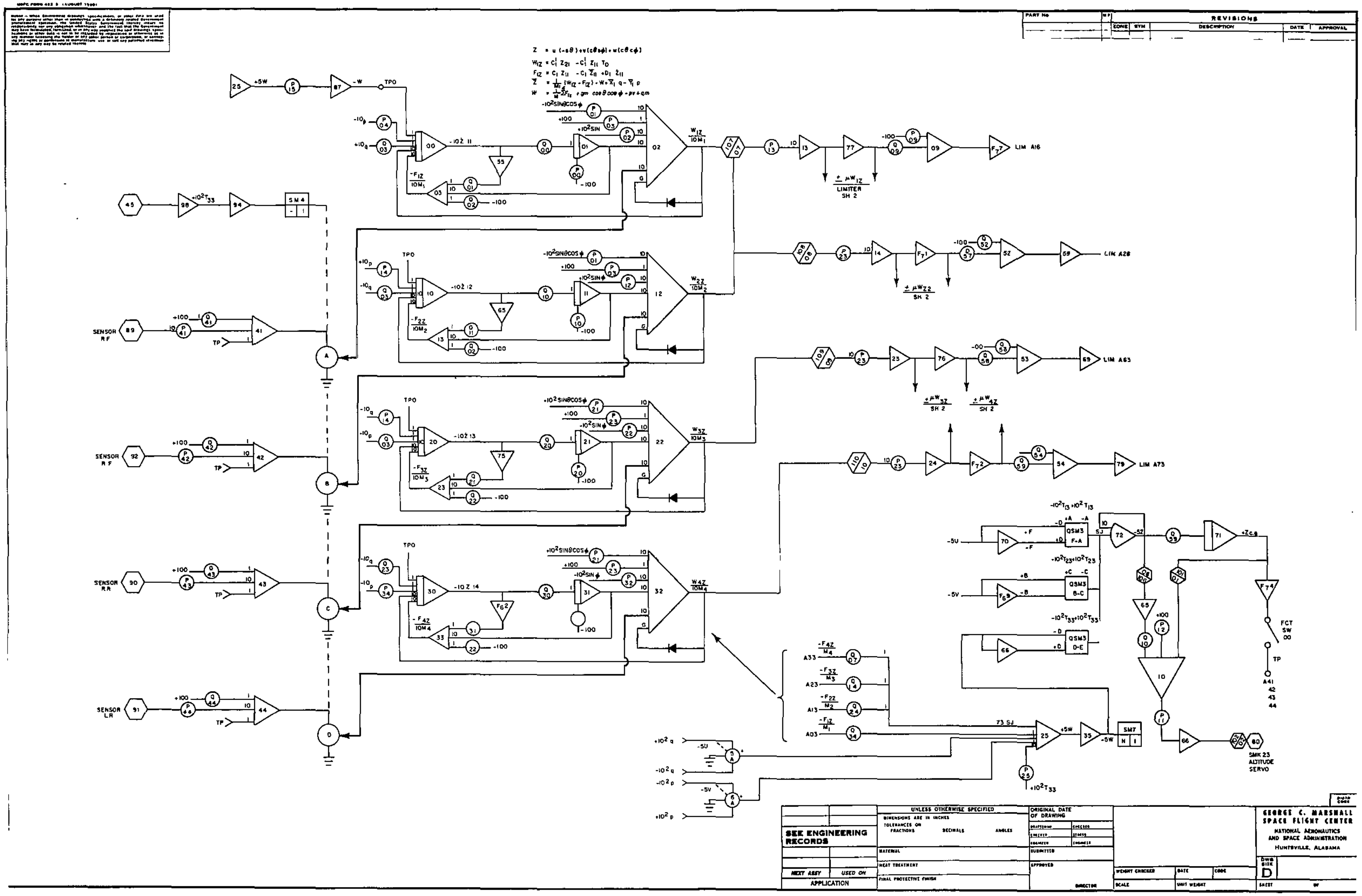

FIGURE 18. COMPUTER PROGRAM

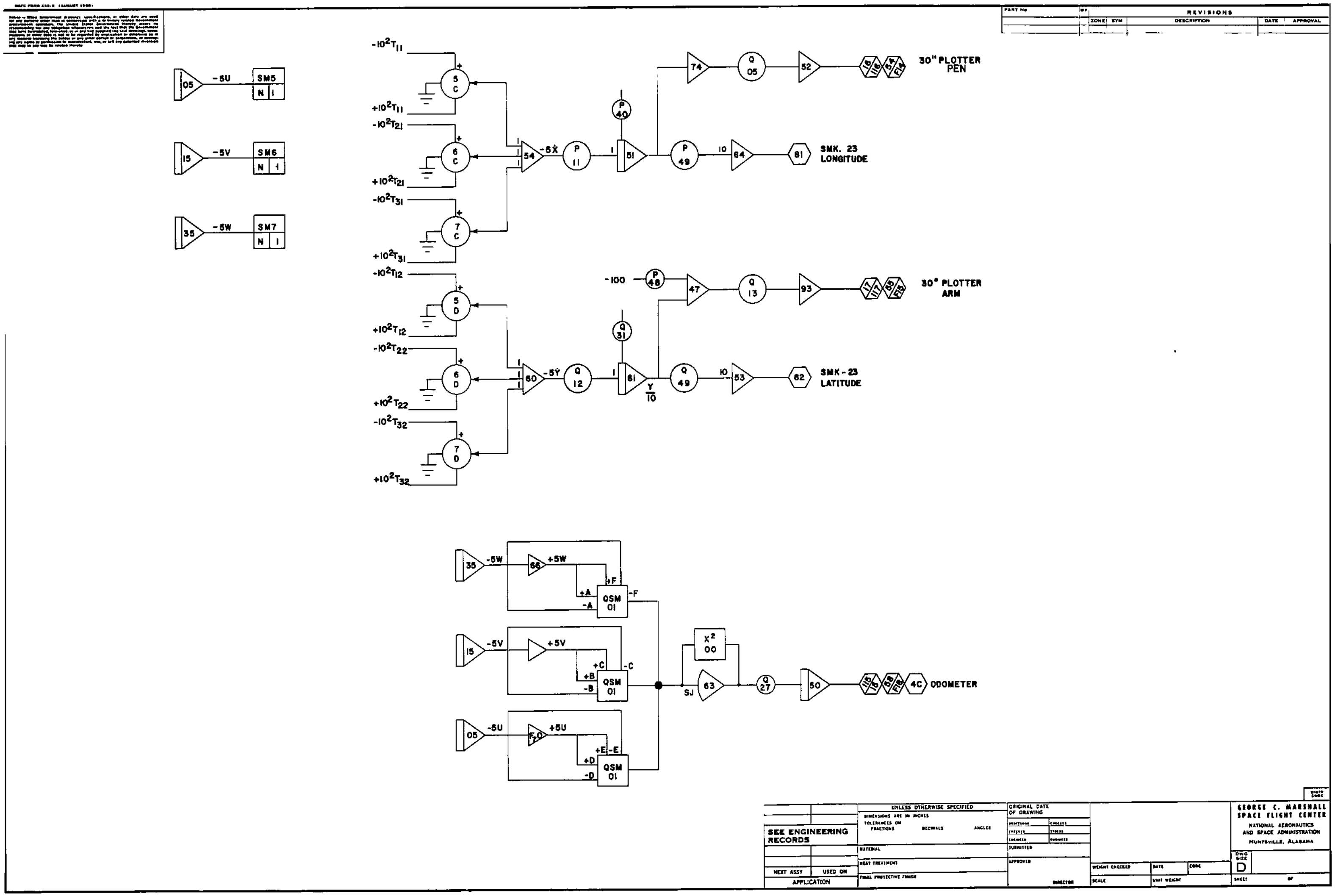

FIGURE 19. COMPUTER PROGRAM

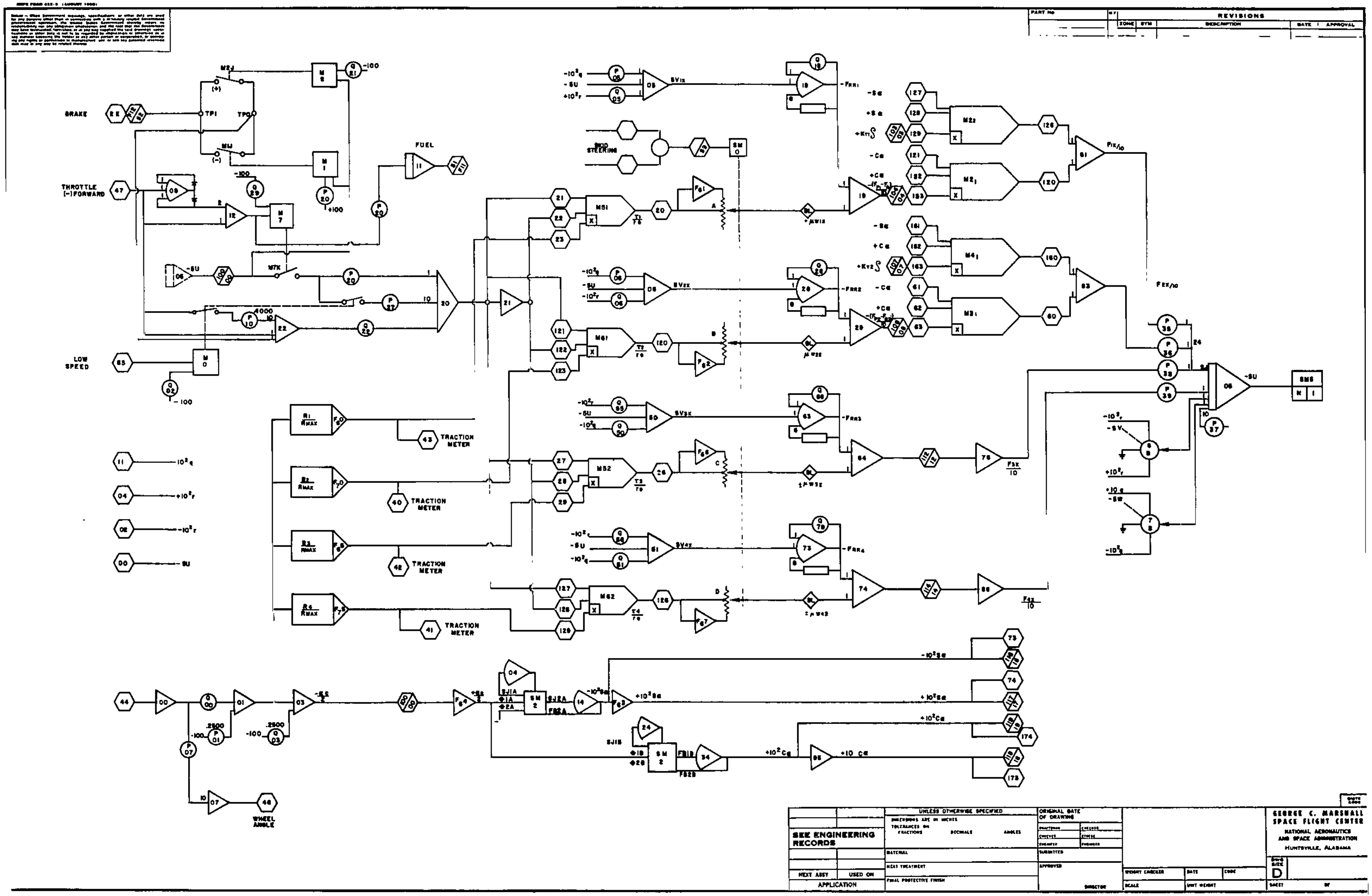

FIGURE 20. COMPUTER PROGRAM

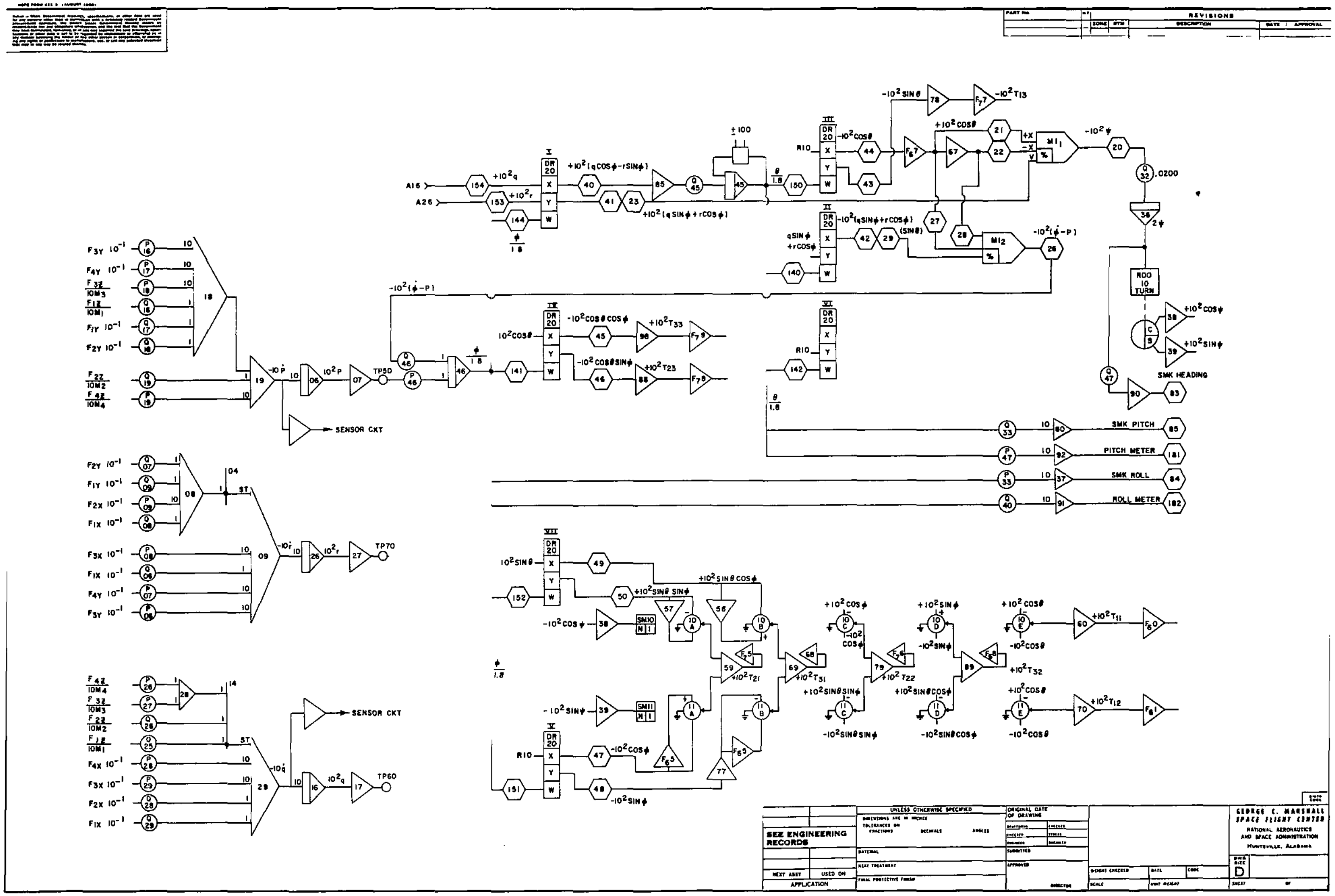

FIGURE 21. COMPUTER PROGRAM

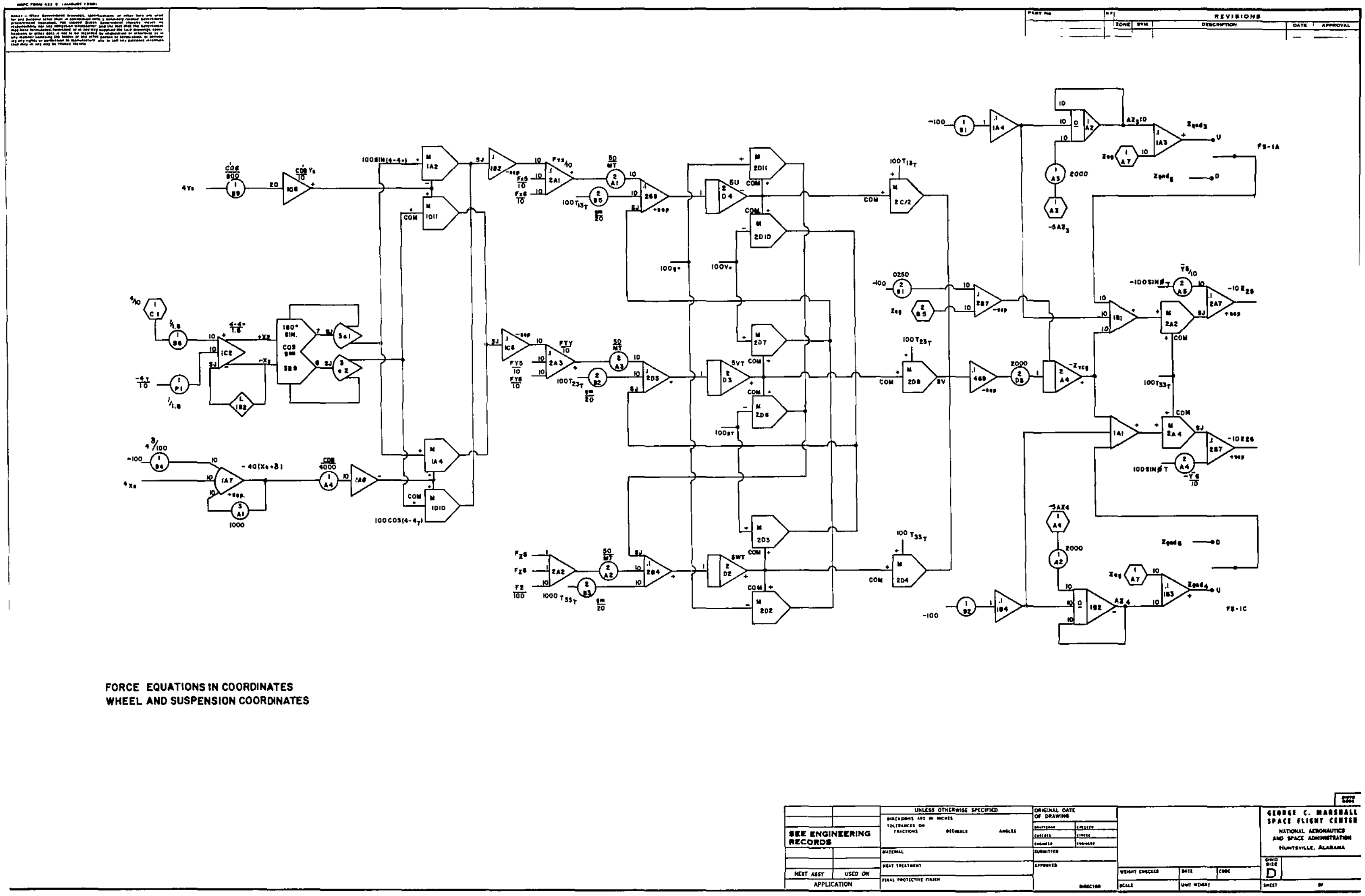

FIGURE 22. COMPUTER PROGRAM

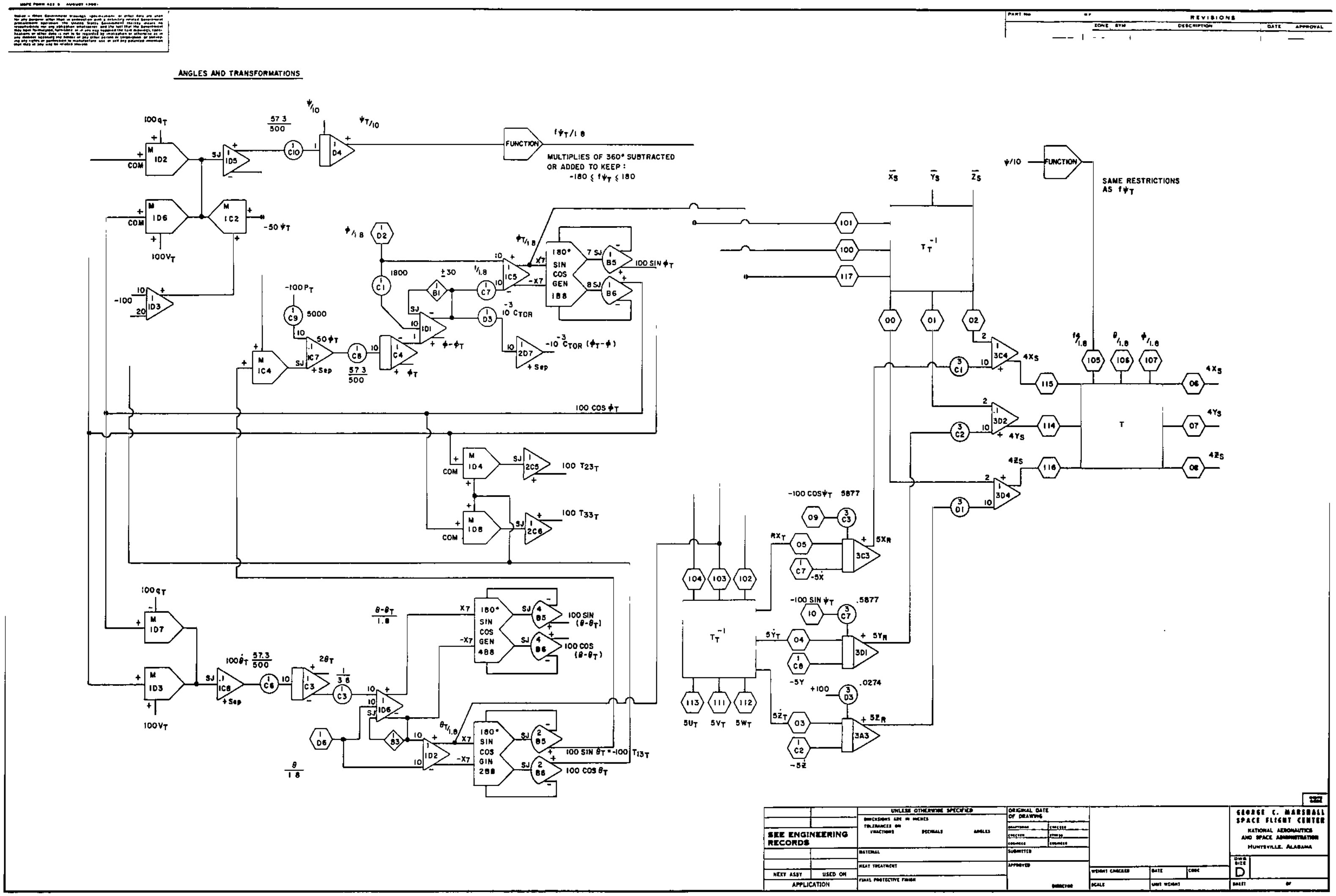

FIGURE 23. COMPUTER PROGRAM

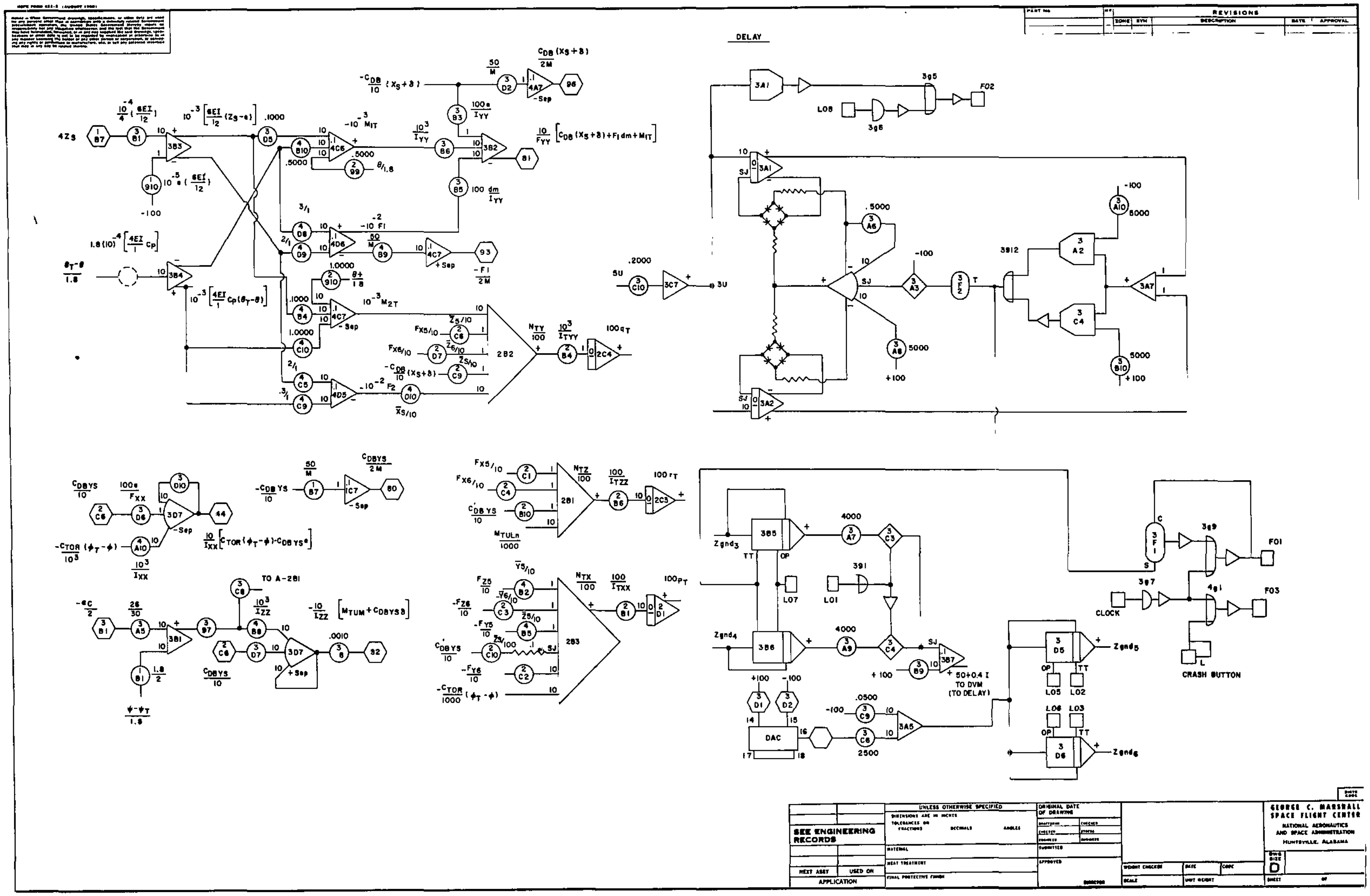

FIGURE 24. COMPUTER PROGRAM

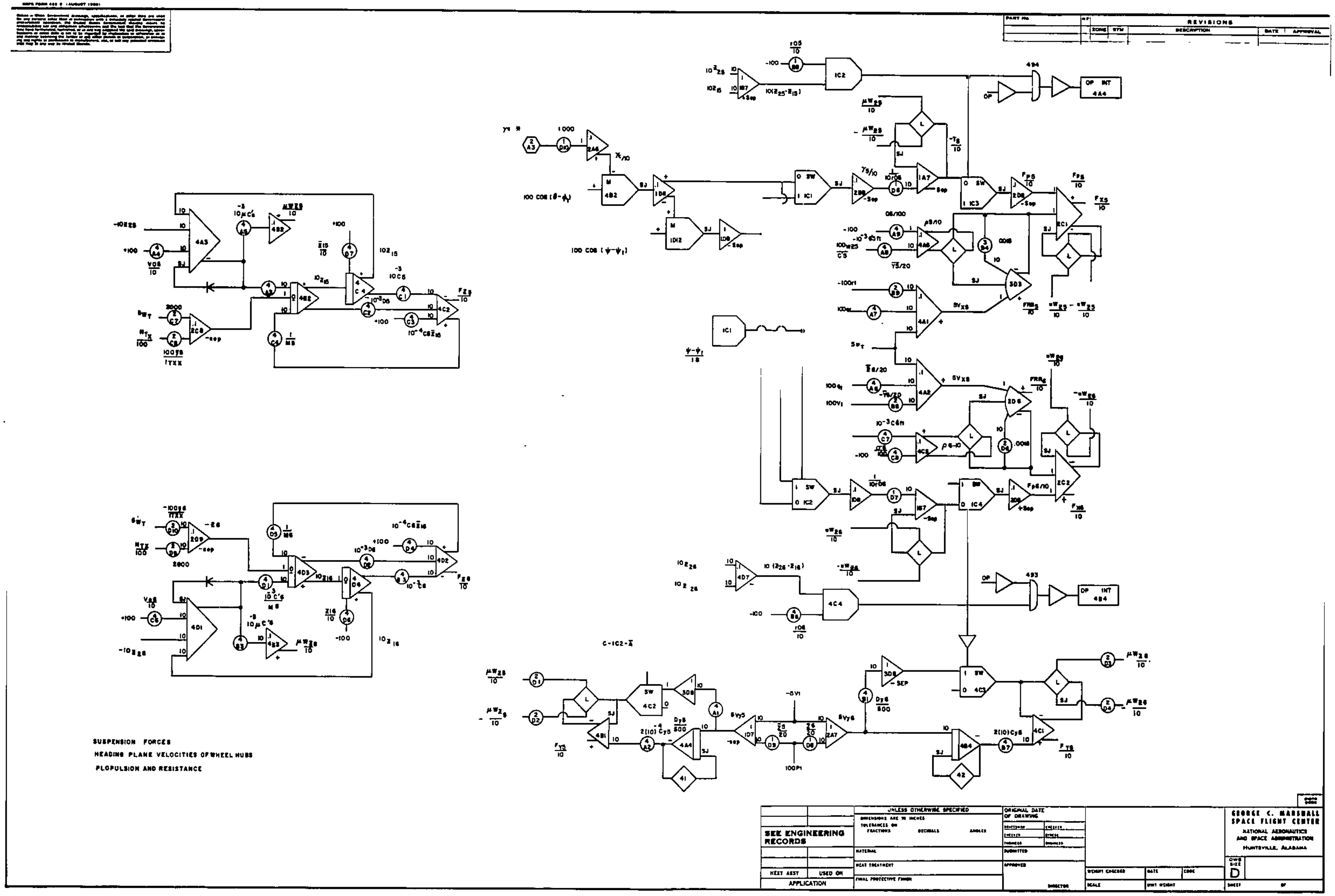

FIGURE 25. COMPUTER PROGRAM

VII. IMPROVEMENTS IN THE CURRENT SYSTEM

The following improvements are now being made which will increase the capabilities of the present simulator, extending its application to other man/machine simulations.

1. Extension of altitude capability by installing a second SMK-23 visual simulator. The present terrain model scaled 150:1 has a maximum altitude capability of 100 feet. This will be extended by providing the second unit with a model of larger scale ratio, and electronically switching from one unit to the other. The extended altitude would make the system applicable to lunar flying vehicle simulations.

2. Addition of a moving base system which will provide pitch, roll and heave motion cues for man/machine simulations, reducing the limitations inherent in fixed base simulators used for studying dynamic vehicle concepts. Control loading will also be incorporated in the system.

3. The development of wide angle optical probes adaptable to the SMK-23 simulator will allow open cockpit simulations. Optical probes being studied will have an ultimate field of view of 60 degrees vertical by 210 degrees horizontal. Also, the development of a virtual image display system will add realism to the scene viewed by the operator.

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National Aeronautics and Space Administration
Huntsville, Alabama, October 1, 1967
127-51-03-01

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