Technical Memorandum No. 33-197

Space Simulator Facilities at the Jet Propulsion Laboratory

Space Simulator Staff

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

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ABSTRACT

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This Report describes the space simulator facilities presently available at JPL. The description includes temperature, pressure, and irradiation capabilities, test instrumentation available, and data handling capabilities.

I. INTRODUCTION

The Jet Propulsion Laboratory has two facilities for simulating the interplanetary environment of extreme cold, high vacuum, and intense solar radiation. The 25-ft space simulator has been operating continuously since 1962 for tests of *Ranger, Mariner,* and *Surveyor* spacecraft and/or their components. The 10-ft space simulator is under construction and is scheduled for shakedown and calibration during May and June, 1965.

Typical test programs have included tests to verify the adequacy of a spacecraft's temperature control system, mission tests to verify that a spacecraft's systems will operate satisfactorily during a simulated mission, solar panel performance tests, midcourse rocket motor firing interaction tests, and combined launch pressure change and vibration tests.

This Report contains information relative to facility performance and capability.

A. General Description of the 25-Ft Space Simulator

The physical arrangement of the 25-ft facility is shown in Fig. 1, and the space simulator is shown schematically in Fig. 2. The vacuum chamber is a right circular cylinder, 27 ft in diameter and 52 ft high. The top head of the chamber contains a 25-ft diameter parabolic collimating mirror. The bottom head, which extends 5 ft below floor level, contains 12 "feed through" or instrumentation ports for making electrical and mechanical connections to spacecraft and test equipment inside the vacuum chamber. The bottom of the chamber is also

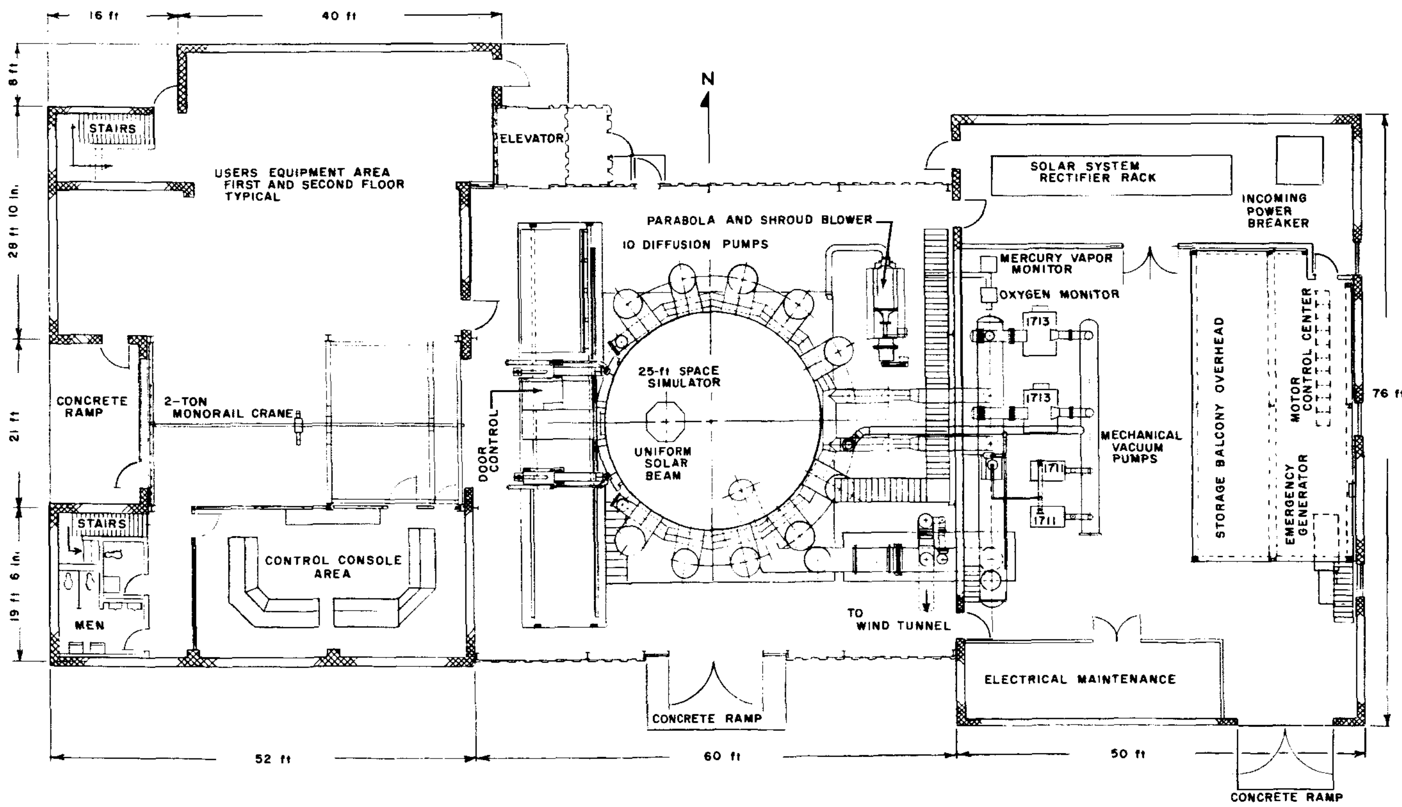


Fig. 1. First floor plan of the 25-ft space simulator area

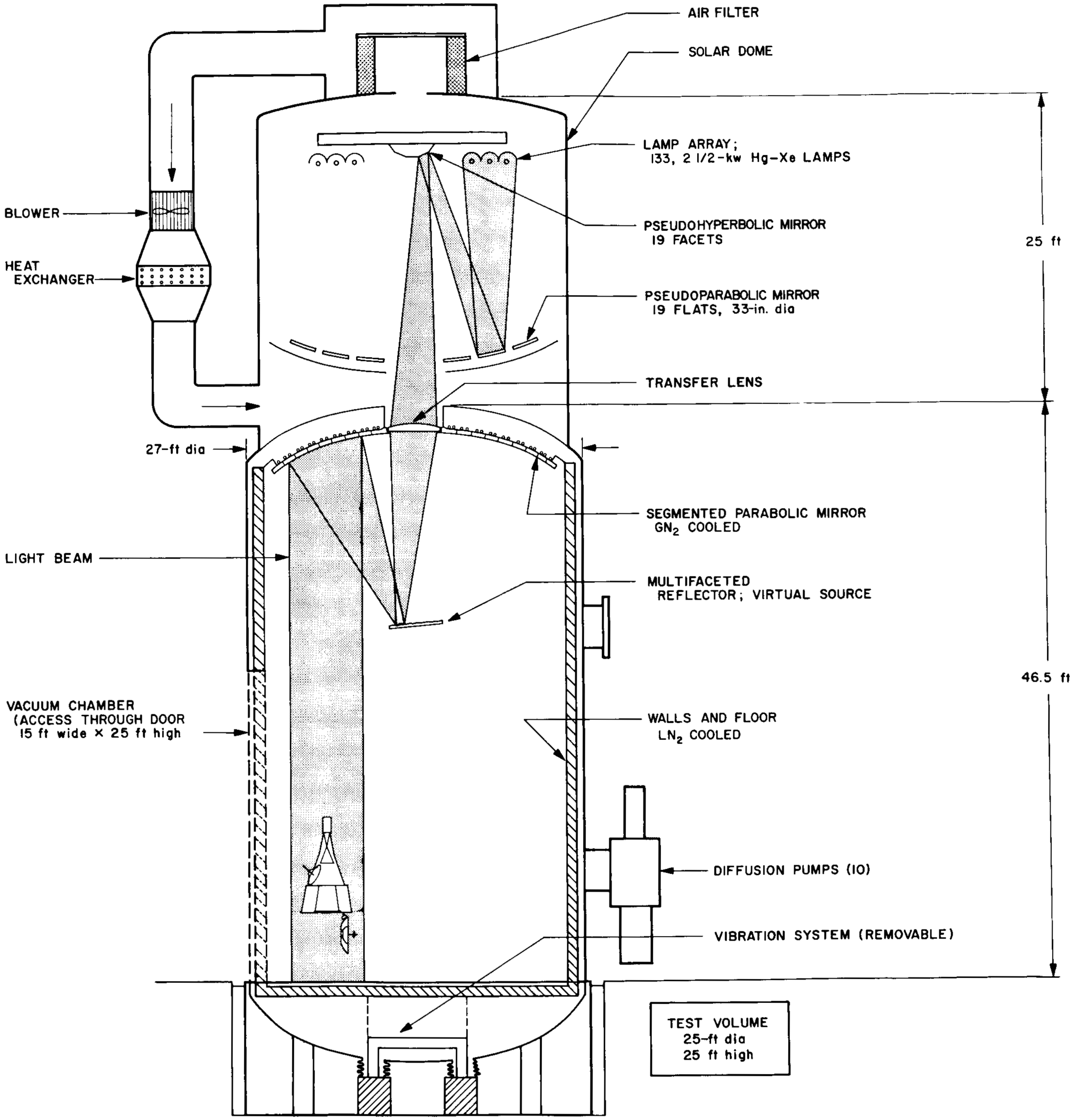


Fig. 2. Cross-section of the 25-ft space simulator

provided with a separately supported platform for mounting a vibration driver. A number of small windows are located at two elevations in the vacuum tank for visual observation of the test item. The vacuum pumping system is shown in Fig. 3.

A cylindrical solar dome caps the vacuum chamber and increases the overall height of the simulator to 80 ft. Simulated solar radiation, originating from 2.5-kw compact arc lamps in the solar dome, passes into the vacuum chamber through a 36-in. diameter fused silica

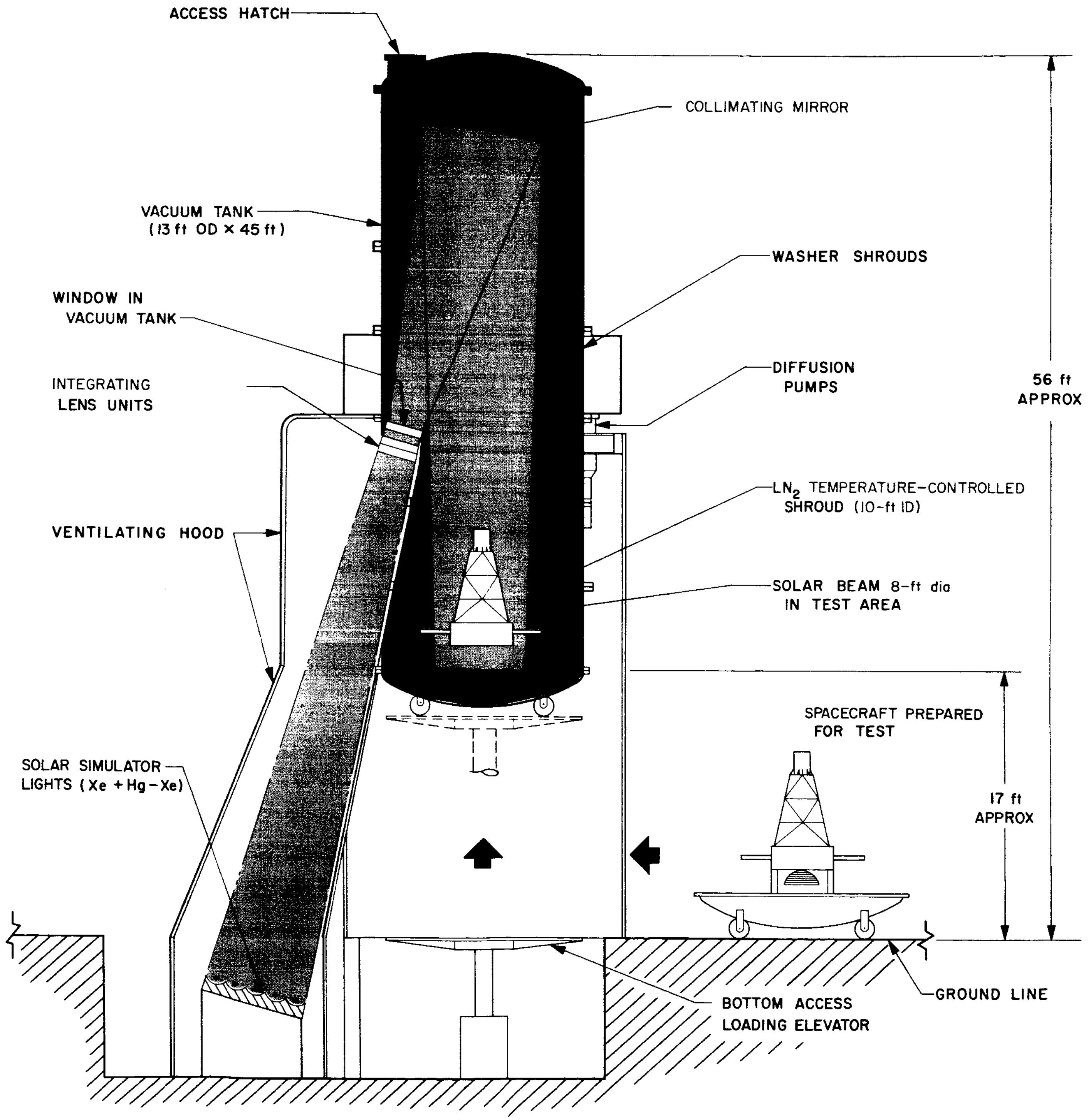
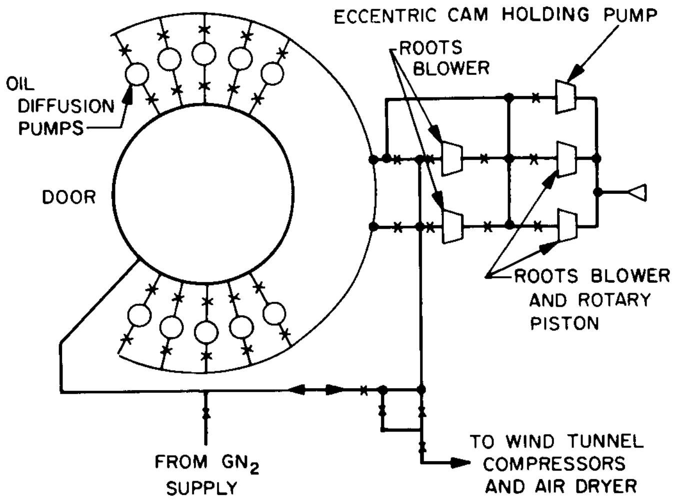


Fig. 5. Cross-section of the 10-ft space simulator



PUMP TYPE	MAKE	MODEL	RATING
OIL DIFFUSION	CVC[a]	PMC-45,000A	45,000 l/sec
ECCENTRIC CAM	KINNEY	KDH-130	130 ft^3/min
ROOTS BLOWER	STOKES	1713	6370 ft^3/min
ROOTS BLOWER AND ROTARY PISTON	STOKES	1711	1250 ft^3/min (blower) 300 ft^3/min (piston)
[a]CONSOLIDATED VACUUM CORP			

Fig. 3. Vacuum pumping system for the 25-ft space simulator

lens mounted in a cylindrical well in the top of the chamber. The light reflects from the multifaceted reflector (virtual source) onto the cooled parabolic mirror which directs the radiation into the test area as an "off-axis" collimated beam. A servo-controlled iris is used to maintain a constant level of solar intensity and to cut off the solar beam (for simulation of Earth shadow) without turning off the arc lamps.

The heat sink of deep space is simulated by liquid-nitrogen-filled black panels (shrouds), which line the walls and bottom of the vacuum chamber. Test items enter the chamber through the 15 × 25 ft door noted in Fig. 1 and 2. A 2-ton overhead crane can be extended into the chamber when necessary. Details of the simulator construction and the design of its present solar simulation system are described in Ref. 1 and 2, respectively.

B. General Description of the 10-Ft Space Simulator

The physical arrangement of the 10-ft facility is shown in Fig. 4, and the space simulator is shown schematically in Fig. 5. The vacuum chamber is a right circular cylinder 13 ft in diameter and 45 ft high. The top head of the chamber contains a 10-ft diameter spherical collimating mirror. The bottom head contains eight "feed through"

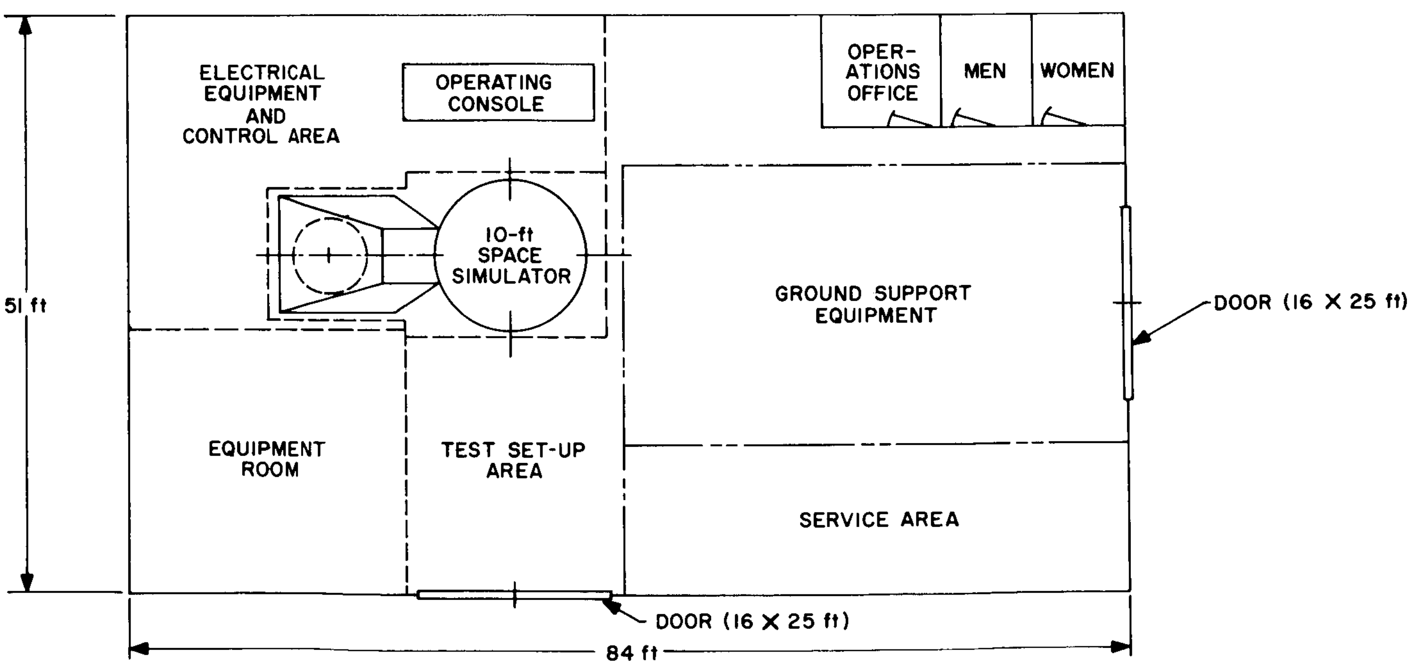
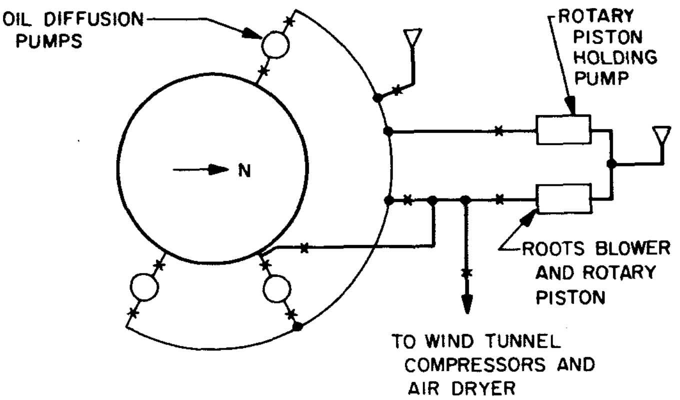


Fig. 4. First floor plan of the 10-ft space simulator area



PUMP TYPE	MAKE	MODEL	RATING
OIL DIFFUSION	CVC[a]	PMC-50,000	50,000 l/sec
ROTARY PISTON	STOKES	148-H	40 ft^3/min
ROOTS BLOWER AND ROTARY PISTON	STOKES	1724	2634 ft^3/min (blower) 300 ft^3/min (piston)

[a] CONSOLIDATED VACUUM CORP.

Fig. 6. Vacuum pumping system for the 10-ft space simulator

ports and is supported by a hydraulic piston for raising the test item into the chamber. The vacuum pumping system is shown in Fig. 6. The walls and bottom of the chamber are lined with liquid-nitrogen-filled black panels.

Simulated solar radiation originates from 5-kw compact arc lamps in the basement below and north of the chamber, and enters the chamber through a 30-in. diameter quartz window on the north side and above the test item. The light impinges on the one-piece collimating mirror, which reflects the radiation into the test area as an "off-axis" collimated beam. The design of the solar simulation system is described in Ref. 3.

C. *Test Volume Size*

For tests that do not require solar simulation, the test volume is nominally the volume enclosed by the shrouds as shown in Fig. 2 and 5. When solar simulation is required, the test volume depends on the size of the solar beam. The solar beam in each chamber is hexagonal or circular in cross-section and somewhat barrel-shaped (Fig. 7 and 8).

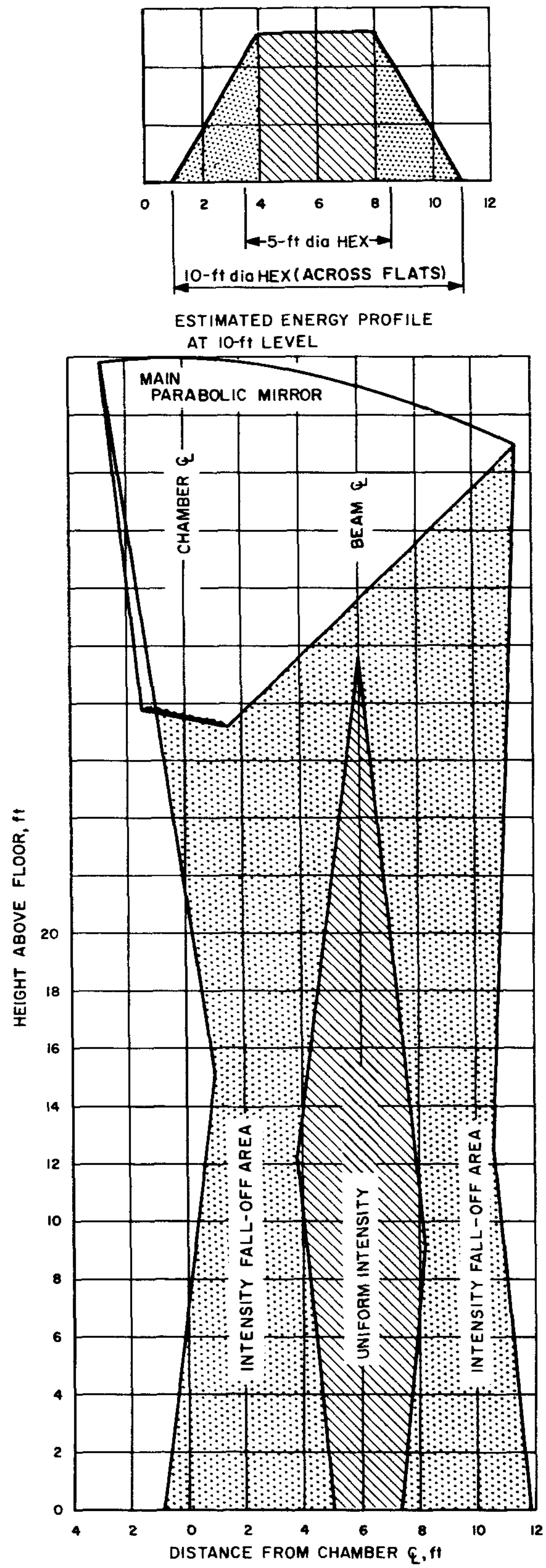


Fig. 7. Irradiated test volume in the 25-ft space simulator (from Ref. 2)

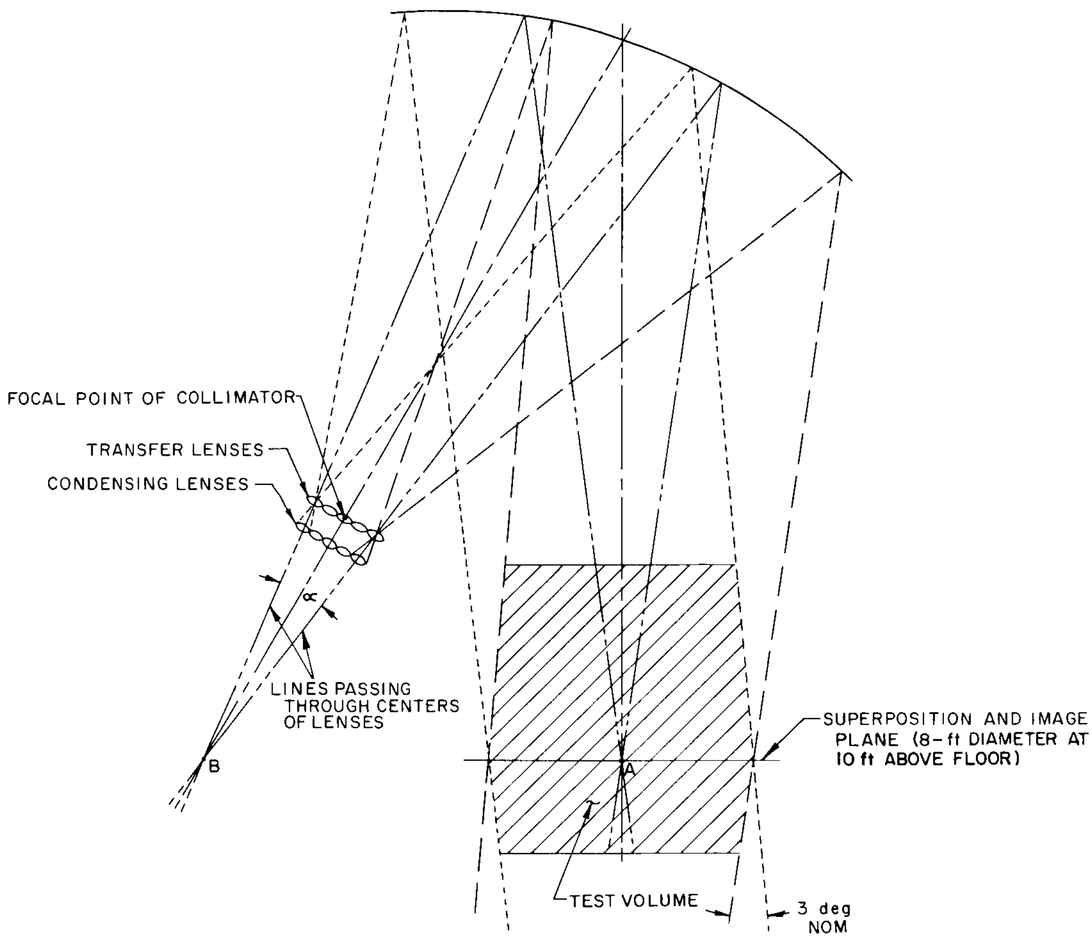


Fig. 8. Irradiated test volume in the 10-ft space simulator (from Ref. 3)

II. ENVIRONMENTAL SIMULATION

Pressure and temperature ranges for the 25-ft and 10-ft space simulators are shown in Table 1. The performance of the solar simulation systems is described in Part III of this Report.

Certain launch pressure profiles can be approximated in either space simulator. The rate of maximum pressure drop in the 25-ft space simulator is shown in Fig. 9. The rate for the 10-ft simulator is expected to be slightly

Table 1. Pressure and temperature ranges

	25-ft space simulator	10-ft space simulator
Pressure (torr)	760 to 5 × 10^{-6}	760 to 1 × 10^{-6}
Effective wall temperature (°F)	−270	−270

greater. This pumpdown capability is particularly helpful in examining pressure-sensitive problems which may occur during the launch of a spacecraft.

A vibration system as powerful as 28,000 force-lb can be installed at floor level inside the 25-ft space simulator, as shown in Fig. 10. Vibrations generated by the vibration system are isolated from the space simulator structure.

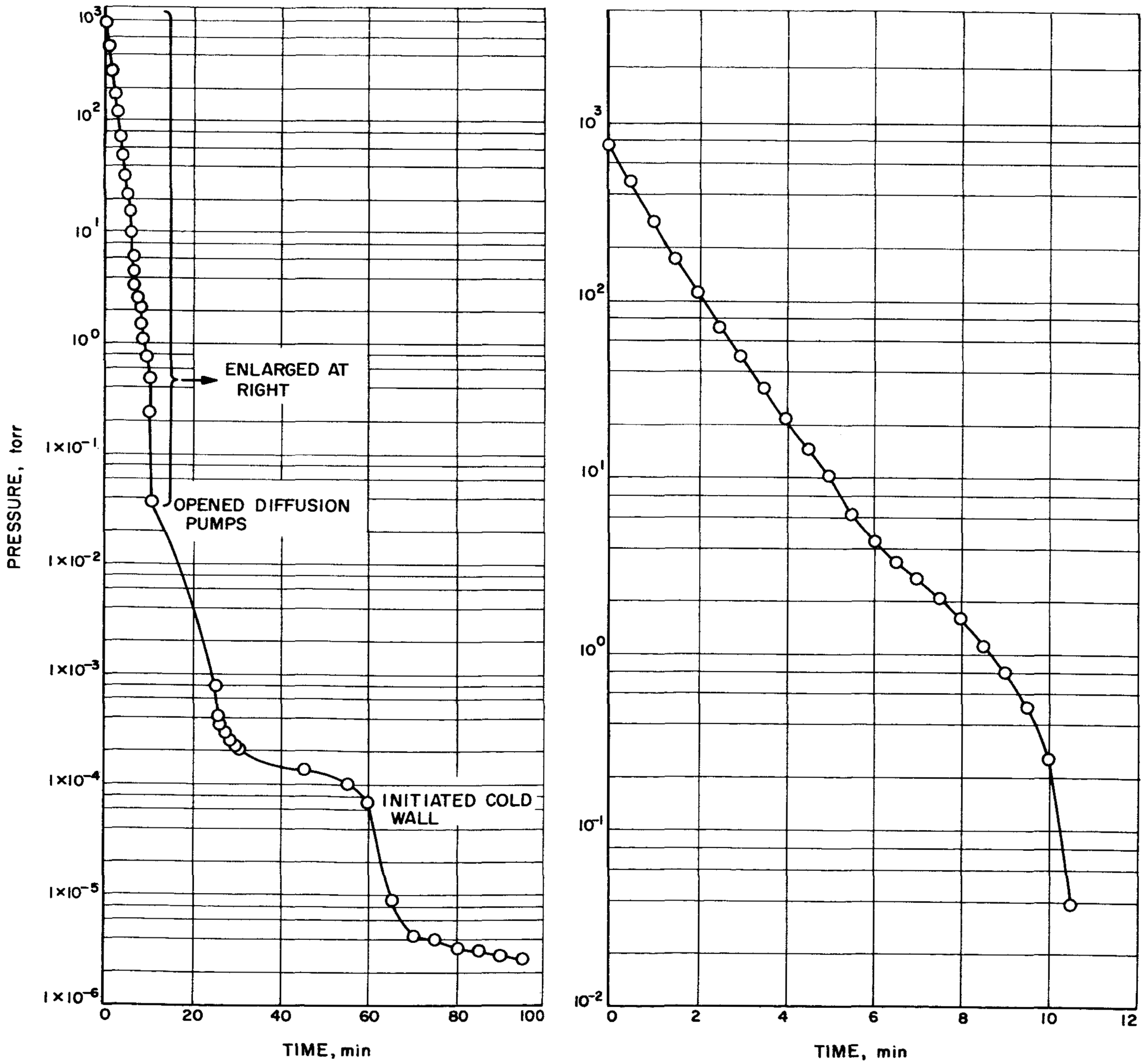


Fig. 9. Maximum rate of pressure drop in the 25-ft space simulator

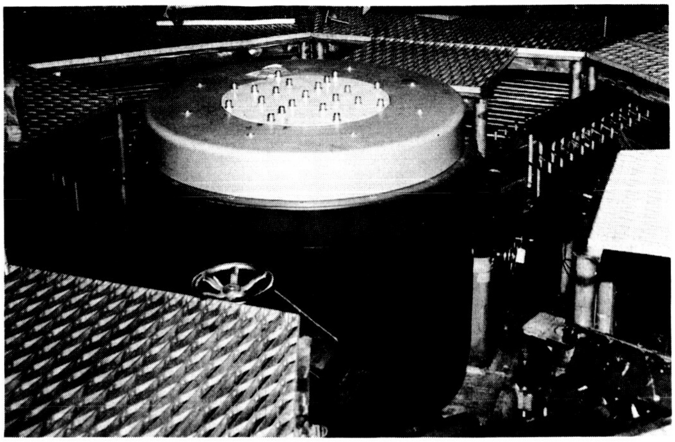


Fig. 10. 25,000 force-lb vibration exciter installed in the 25-ft space simulator

III. SOLAR SIMULATOR CALIBRATION

The solar simulator performance for both space simulators is listed in Table 2 and discussed in more detail below.

Table 2. Solar simulator performance

	25-ft space simulator	25-ft space simulator modified[a]	10-ft space simulator
Uniformity	±3%	±5%	±5%
Beam size (diameter)	4-ft hex.	15-ft hex.	8-ft dia
Intensity (w/ft²)	0 to 190	0 to 130	0 to 250
Beam divergence	±5.3 deg	±2 deg	±1.5 deg
Spectrum	Hg-Xe	Xe and Hg-Xe	Xe and Hg-Xe

[a]This improvement will be accomplished between August, 1965 and July, 1966 with a solar system like that in the 10-ft space simulator.

A. 25-Ft Space Simulator

1. Beam Size and Uniformity

The light beam is hexagonal in cross-section and measures 4 ft or more across the flats, depending on the required uniformity. The uniformity of solar energy distribution is independent of intensity level and is shown in Fig. 11 for a nominal intensity of 184 w/ft^2. A second virtual source is available, which increases the ±3% area of the beam to 5 ft across the flats of a hexagon, at some sacrifice in intensity.

2. Intensity

The maximum irradiation intensity obtainable for an initial 12-hr period (with no lamp replacement) is 190 w/ft^2 (202 mw/cm^2). This figure allows for a 5% lamp loss during the 12-hr period. Using the virtual source which provides the larger beam, 124 w/ft^2 (133 mw/cm^2) is the maximum intensity available for a similar 12-hr period. An intensity of 130 w/ft^2 can be run continuously for periods up to 400 hr. It takes 24 hr to change the virtual source.

The intensity is normally controlled between 0 and 190 w/ft^2 by a silicon solar cell, which regulates an iris opening located just above the fused silica lens. This control will maintain the intensity within ±0.2 w/ft^2. The intensity level is normally set manually by monitoring an

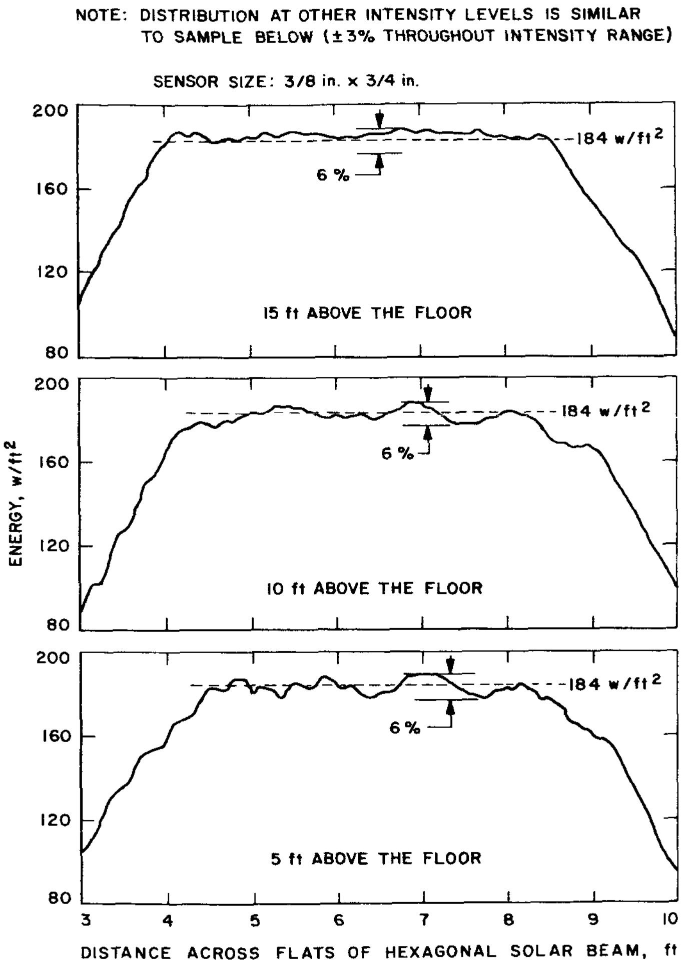


Fig. 11. Solar energy distribution in the 25-ft space simulator

Eppley Mark I radiometer while adjusting the iris control point.

The water-cooled iris is able to completely eclipse the solar beam, and requires a maximum of 4 min to close. A "hard-hat" is provided below the iris to immediately cut off the beam while the iris is closing, if this condition is a test requirement. The reverse process may also be used for step-function turn-on, but the hard-hat is not cooled and is limited to approximately 4 min of exposure to full irradiance.

3. Beam Divergence

The "collimation" half-angle of the present simulator is 5.3 deg. However, it is possible for some light to leave the outermost lamps and go directly through the lens to the test volume. Using the Eppley Mark IV filter radiometer, it was found that a small but measurable amount of energy existed between 10 and 15 deg (total angle). JPL also has an Eppley Mark VII radiometer, designed specifically to measure intensity vs beam divergence by increasing its aperture openings in 1-deg steps from 2 to 20 deg (total angle). This device has not yet been used due to the pressure of spacecraft test schedules.

4. Spectrum

The spectrum (Fig. 12) is basically mercury-xenon, modified slightly by five mirror reflections and one lens refraction. Figure 12 shows the result of a second attempt by the Eppley Laboratory, Inc. to determine the light beam spectrum during an 8-day period in October and November, 1964. The equipment consisted of an Eppley Mark V filter radiometer, a Jarrell–Ash grating monochrometer, and a Perkin–Elmer prism monochrometer. These instruments are described in Part V, and the technique used is outlined in Ref. 4.

B. *10-Ft Space Simulator*

Calibration of the 10-ft solar simulator will be accomplished in May and June, 1965, using techniques developed during similar investigations of the present 25-ft solar simulator and during tests of the full-scale mock-up of the 10-ft solar simulator. The following discussion is based on the test results of the full-scale mock-up (see Ref. 3).

1. Beam Size and Uniformity

The test volume is circular in cross-section and is 8 ft in diameter. The uniformity, as measured with a sensor not larger than 2 in. in diameter, is specified as follows:

1. In any horizontal plane, the intensity shall not vary by more than 5% of the mean value for that plane.

2. Within the test volume, the intensity shall not vary by more than 10% of the mean value for the volume.

The full-scale tests indicated that ±5% uniformity in the test volume is obtainable using a ½-in.-square solar cell.

2. Intensity

The solar simulator will be able to provide a stable intensity level at any point between 0 and 250 w/ft².

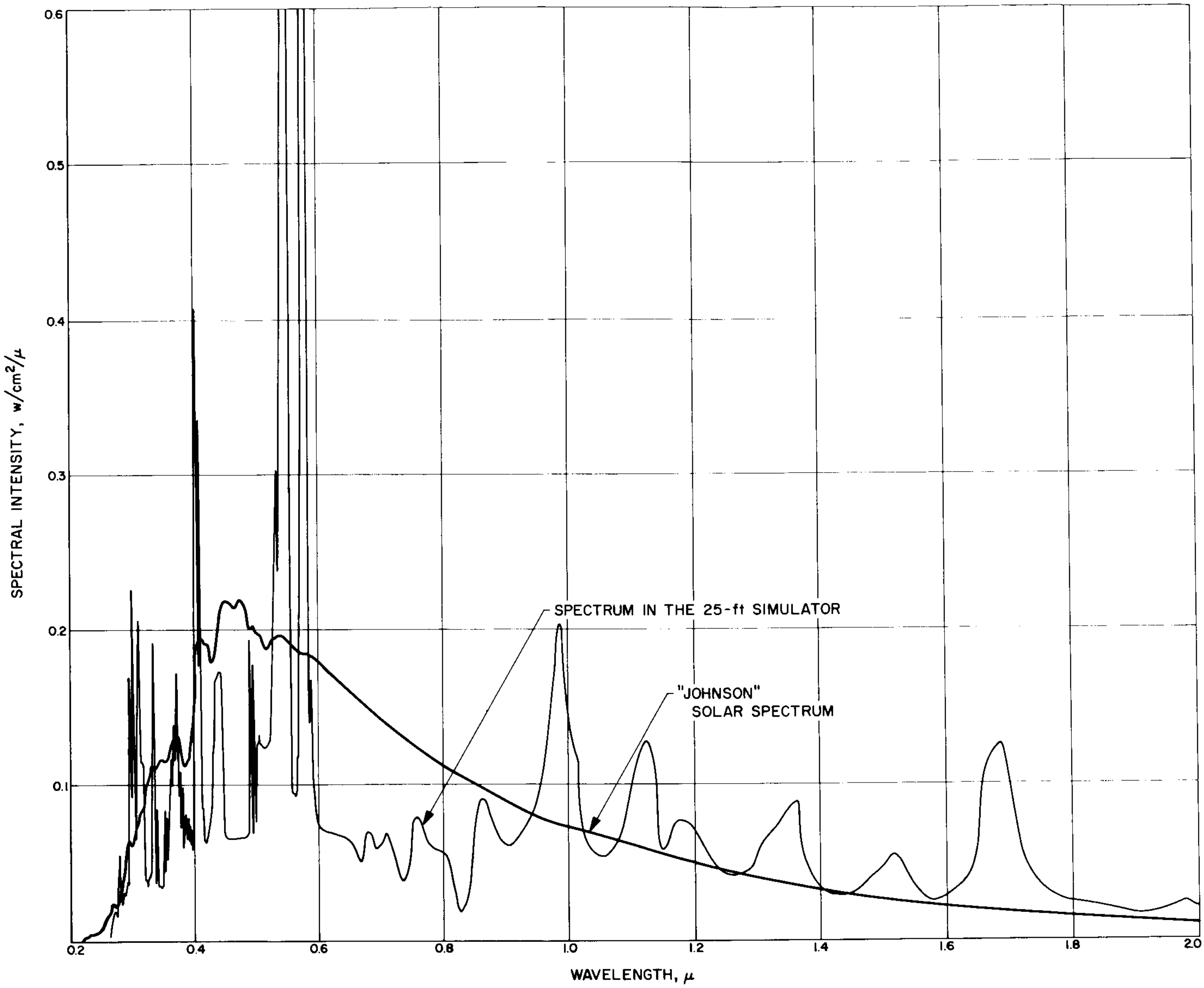


Fig. 12. Energy vs wavelength for the 25-ft space simulator

No iris will be employed. The intensity level will be controlled by the number of lamps in use and by the power (current) supplied to each lamp. A 10-min warmup will be required to obtain a stable intensity within the test volume.

3. Beam Divergence

A 2-deg half-angle was the design goal, and will be obtained using the initial 19 compact arc lamps. However, the facility is designed to accommodate 54 lamps, which will be used to decrease the beam divergence rather than increase the intensity. Calculations indicate that a 0.7-deg half-angle is possible at 130 w/ft^2, using 54 lamps and a stopped-down lens unit.

4. Spectrum

Initially, a ratio of five xenon lamps to one mercury-xenon lamp of equal power input (5 kw) will be used. Since the xenon lamps produce more energy per input kw, this results in a light input energy ratio of 6.7 to 1. Figure 13 indicates the resultant spectrum from such a

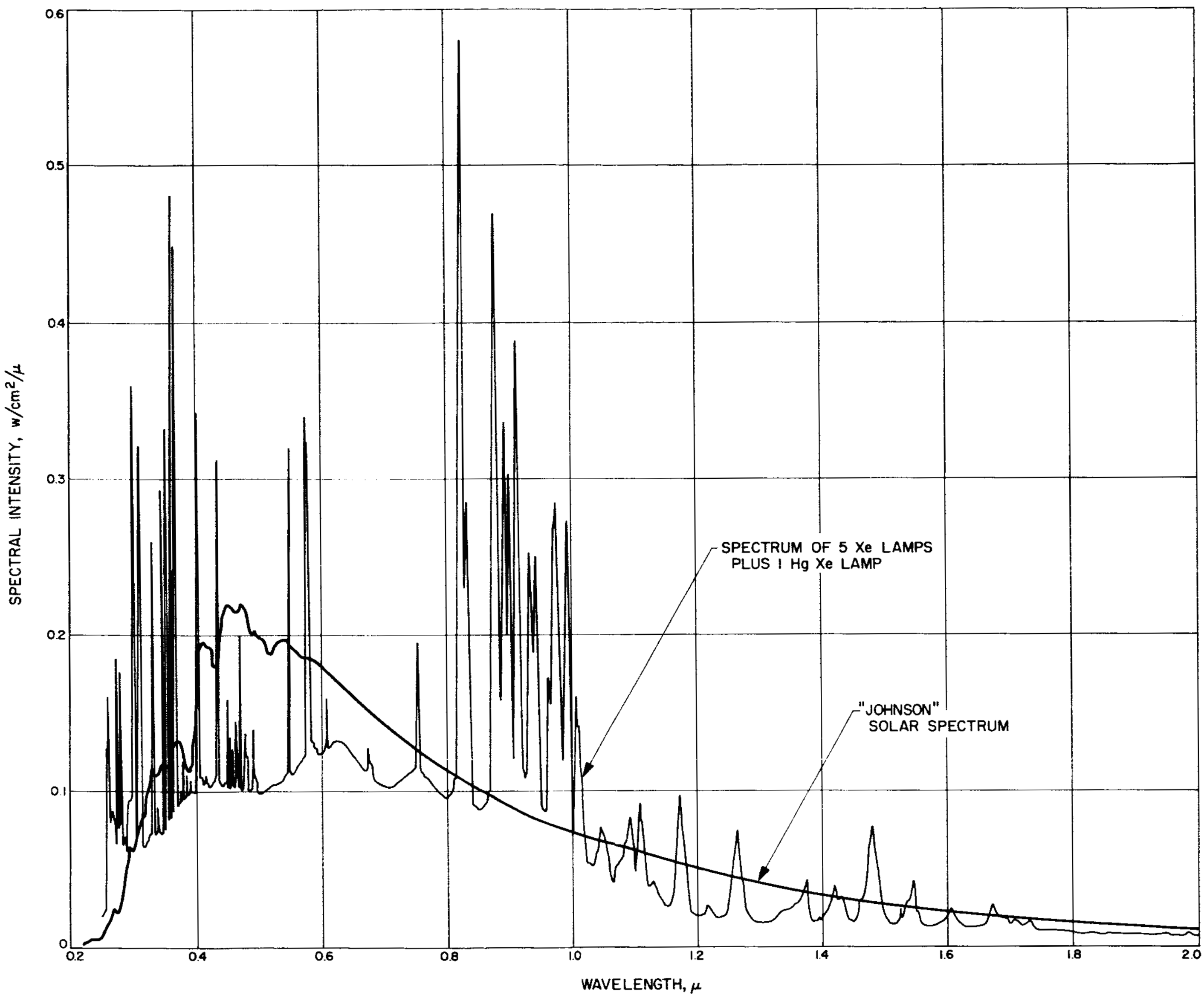


Fig. 13. Energy vs wavelength for a mixture ratio of five xenon lamps to one mercury-xenon lamp

ratio, based on the individual spectra of bare lamps. This spectrum closely simulates the solar spectrum from 0.2 to 0.38 μ, resulting in absorptance similar to solar absorptance for such materials as so-called stable white paints and some gold finishes, as well as for the more spectrally flat surface coatings.

IV. TEST ITEM INSTALLATION

In general, the spacecraft or test item is either hung by cables or hard-mounted from the chamber floor structure. These techniques are shown in Fig. 14 through 17. Two aluminum beams (Fig. 18) are provided just below the collimating mirror, and two more are provided at floor level. These beams act as attachment points for the 3/16-in. stainless-steel support and restraining cables. A hard-mounting technique was used for *Ranger VIII* to minimize the spacecraft motion and thus eliminate saturation of certain gyros in the attitude control system.

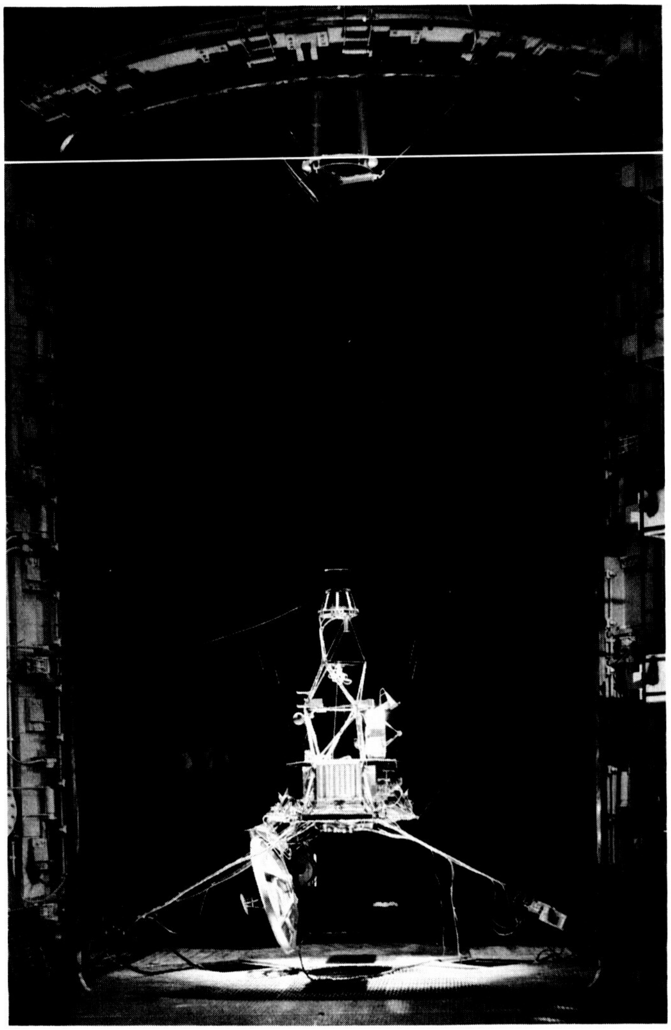


Fig. 14. *Mariner II* in the 25-ft space simulator

Fig. 15. *Surveyor* landing leg in the 25-ft space simulator

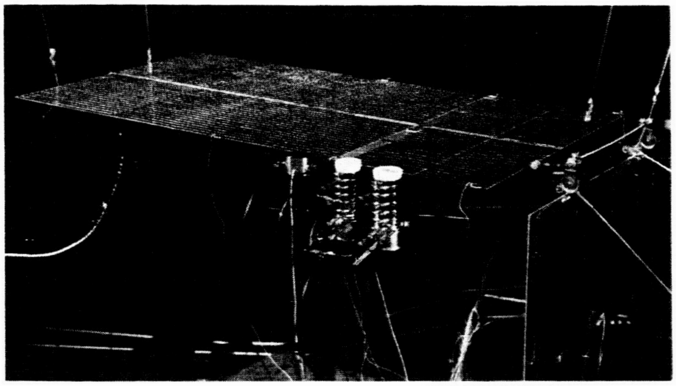


Fig. 16. *Mariner-IV* solar panel in the 25-ft space simulator

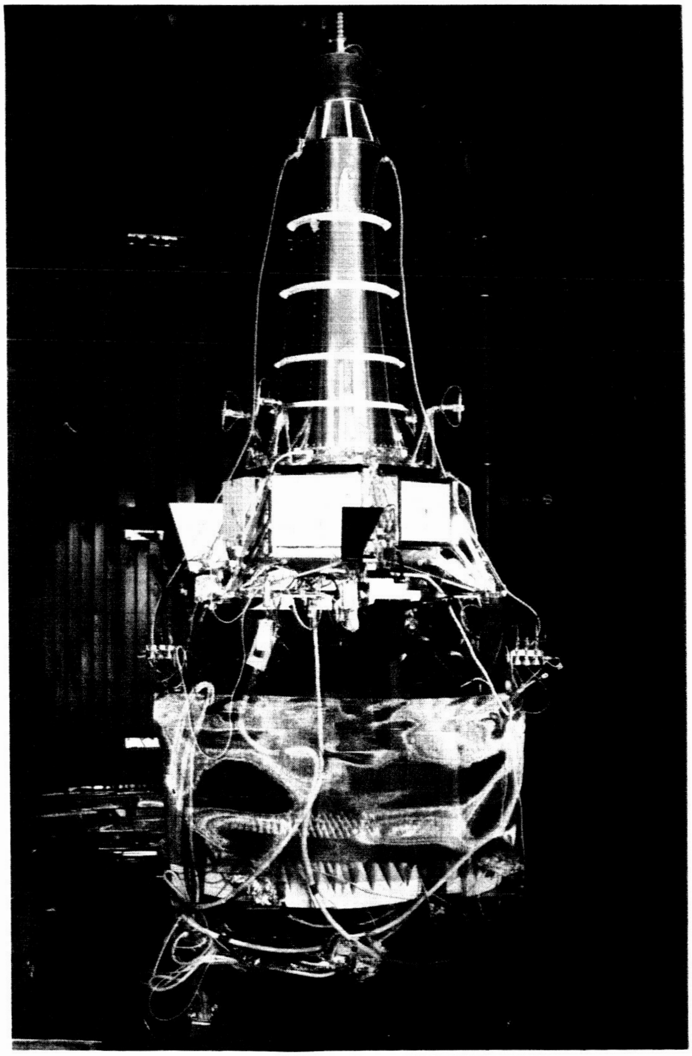


Fig. 17. *Ranger VIII* in the 25-ft space simulator

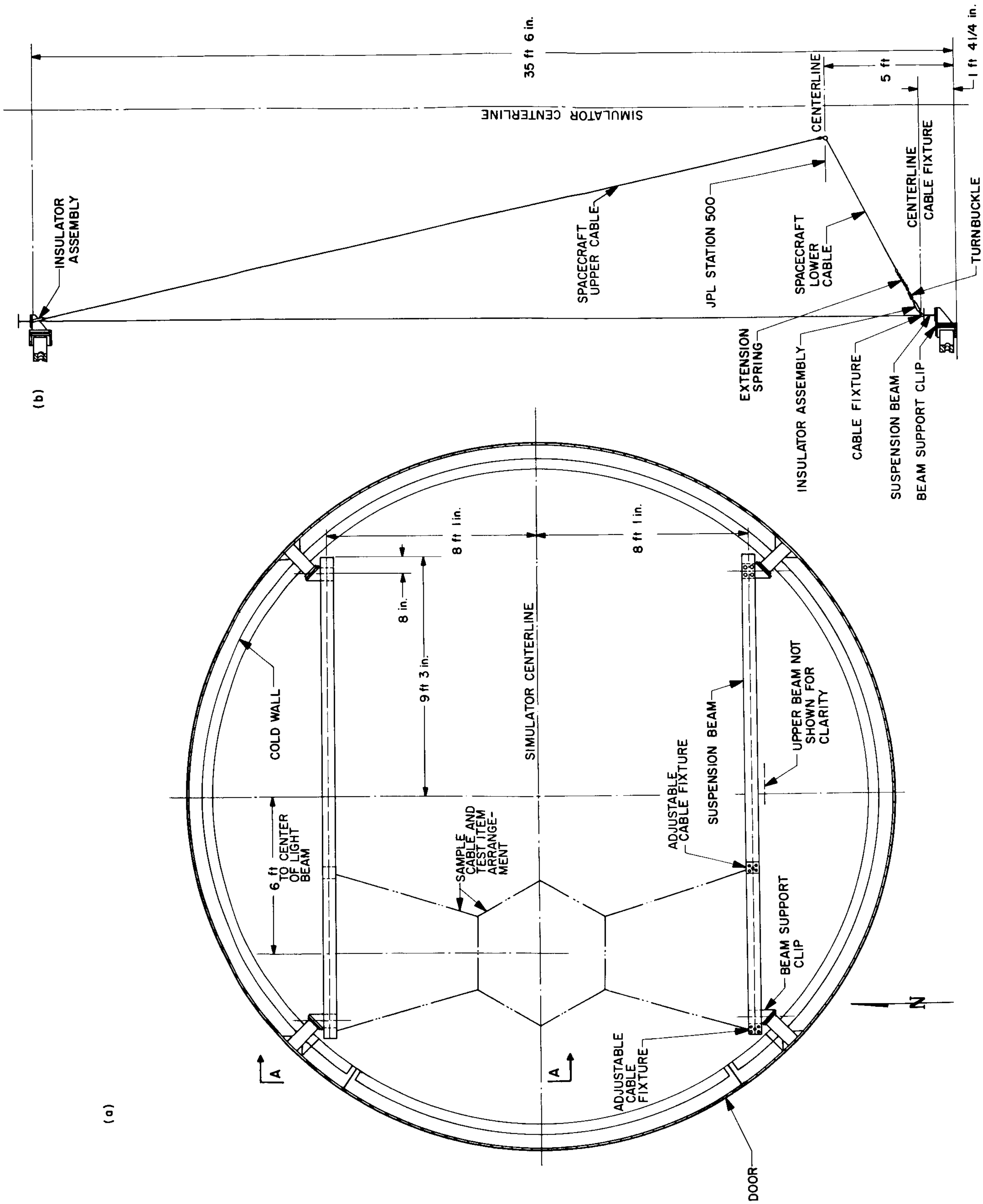


Fig. 18. Suspension fixture assembly for the 25-ft space simulator: (a) plan view, (b) cross-section at A-A

V. TEST INSTRUMENTATION

A. Solar Measurements[1]

The Eppley Mark I radiometer, of which JPL has five, is used to set the solar intensity and monitor it throughout each test.[2] It consists of a 15-junction, bismuth–silver thermopile radiometer with thermistor vacuum compensation for use in vacuum at irradiance levels up to 300 mw/cm² (about 280 w/ft²). The receiving surfaces are 0.9 in. diameter and are coated with Parson's black optical lacquer, which has an emissivity and absorptivity, essentially flat from 0.35 to 40 μ, of 0.98 and 0.95, respectively. The instrument was designed to have nearly a 180-deg viewing angle, but the simulator's cold shroud causes large negative zero readings (requiring a meter or recorder which can conveniently handle such readings). To partially eliminate this problem, temperature-controlled tubular shields 5 in. long have been used with an aperture angle of 32 deg. In the past, these tubes have not been internally baffled (but were painted black), and side-wall reflection increased the reading by 2 to 3%. This problem is now being remedied by tubular shield modification. The instrument is normally temperature controlled by water to ±0.5°F. The operating temperature used is identical to that used during calibration at Eppley. The instrument may be used in air at atmospheric pressure by bypassing the vacuum compensation thermistor, which is inconvenient, or by using a slightly nonlinear calibration curve furnished by Eppley. Without the vacuum compensation, the instrument is linear in air. The sensitivity of about 0.25 mv/w/ft² in vacuum is roughly 2.5 times the air

[1]Equipment for these measurements is available and can be used in both space simulators.

[2]This instrument is described in brochures available from Eppley Laboratory, Inc., Newport, Rhode Island.

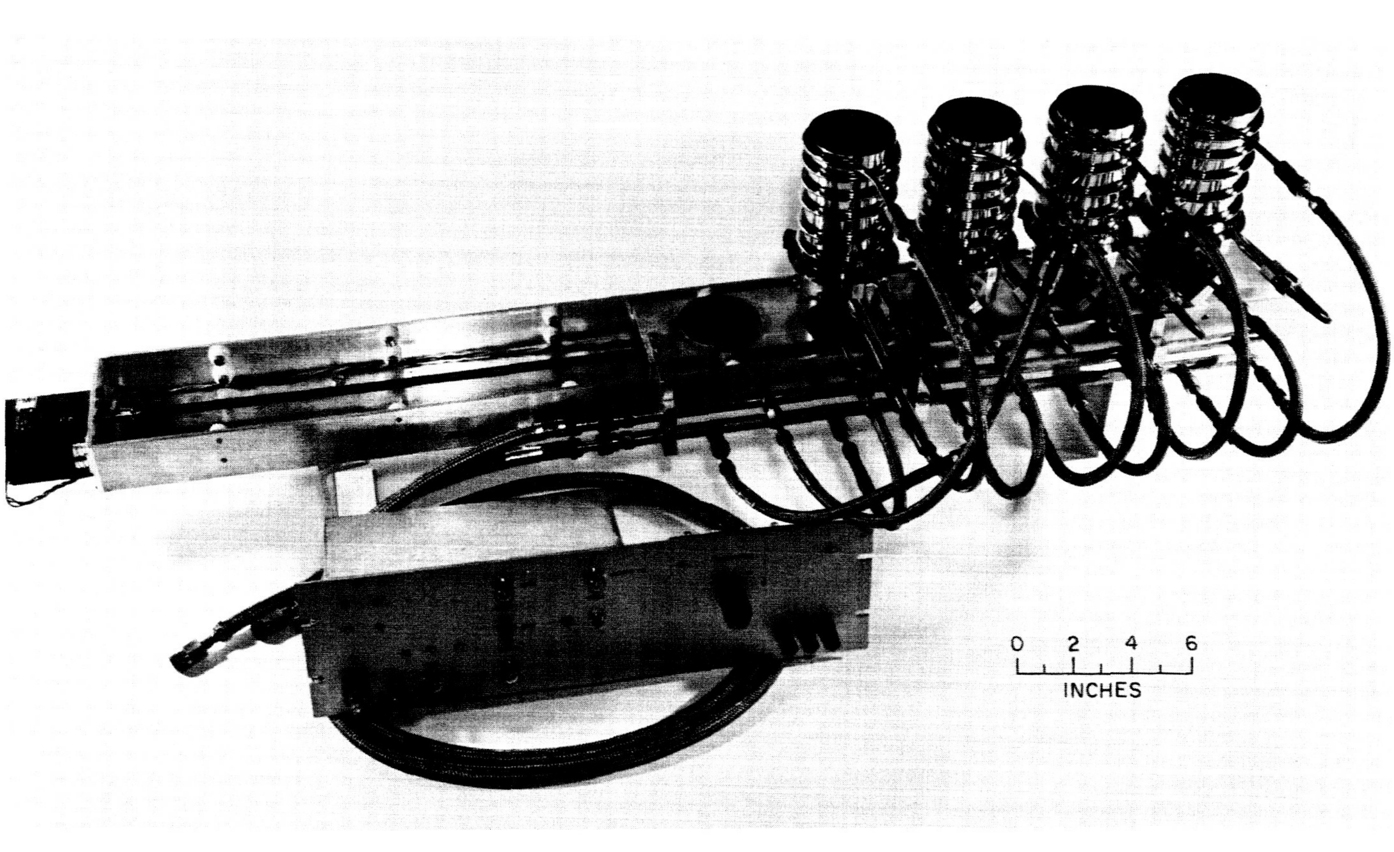


Fig. 19. Eppley Mark I radiometers

sensitivity when the vacuum compensation is retained in both instances. Response time ($1/e$) is approximately 5 sec in air and approximately 15 sec in vacuum. Linearity with vacuum compensation is $\pm 2\%$.

The Eppley Mark I radiometers are periodically calibrated in air at Eppley in a highly diffuse hemisphere lighted along the periphery with the instrument at the center. The intensity level is set up and measured by a 180-deg transfer standard, which is periodically calibrated against the Eppley reference group of working radiometric standards. These standards include three Angstrom primary pyrheliometers that have been standardized to the International Pyrheliometric Scale (1956) and are periodically compared with instruments maintained by the Smithsonian Institute and with others in Sweden, Switzerland, France, and elsewhere. The air-to-vacuum ratio is determined in a relative manner, using a vacuum bell jar and a tungsten lamp.

Figure 19 shows four Mark I radiometers on a device used to sequentially position the instruments in the same location in the simulator for comparative purposes. Recent tests resulted in a $\pm 3\%$ agreement among these four instruments.

The Mark I electrical output is normally recorded on a Speedomax H with AZAR (adjustable zero and range), which allows a ± 2- to ± 100-mv span and a 0-, 10-, 20-, 30-, or 40-mv zero suppression. If additional radiometers are used, their outputs are simply read from a digital millivoltmeter. The Speedomax H accuracy is 0.3% of full scale. The digital millivoltmeter accuracy is $<0.1\%$ of the reading ± 1 digit, and its sensitivity is 10 μv.

The Eppley Mark IV filter radiometer (Fig. 20) measures irradiation at the test location as a function of wavelength. It employs 12 narrow-band filters, which are positioned one at a time over the radiometer from a small, remote console. The bandwidth of each filter is selected according to the source used, different sets of filters being employed for mercury-xenon, xenon, carbon-arc, and tungsten filament lamps. Aperture openings in 1-deg steps from 5 to 15 deg are provided. A suitable opening is selected to accommodate the light beam divergence in the chamber. A remotely rotatable shutter reduces solarization of the filters, and cooling-water coils permit temperature control of the thermopile assembly. The instrument will operate satisfactorily at 10^{-6} torr, under cold-wall conditions. A quartz window is provided for use at atmospheric pressure. The instrument employs a 15-junction, platinum–rhodium/gold–palladium thermopile with a ⅜-in. diameter receiver disc. No pressure compensation is employed. Sensitivity is 0.04 mv/w/ft^2 in air and 0.13 mv/w/ft^2 in vacuum.

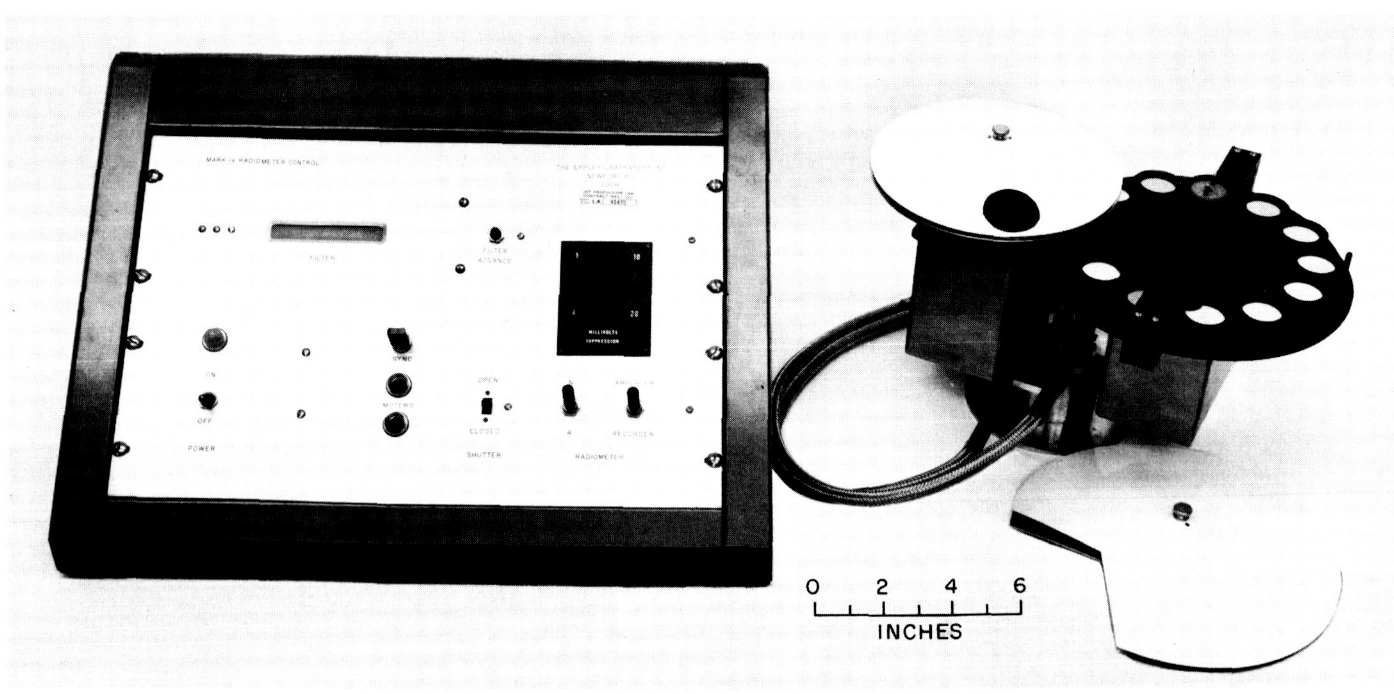


Fig. 20. Eppley Mark IV filter radiometer and control console

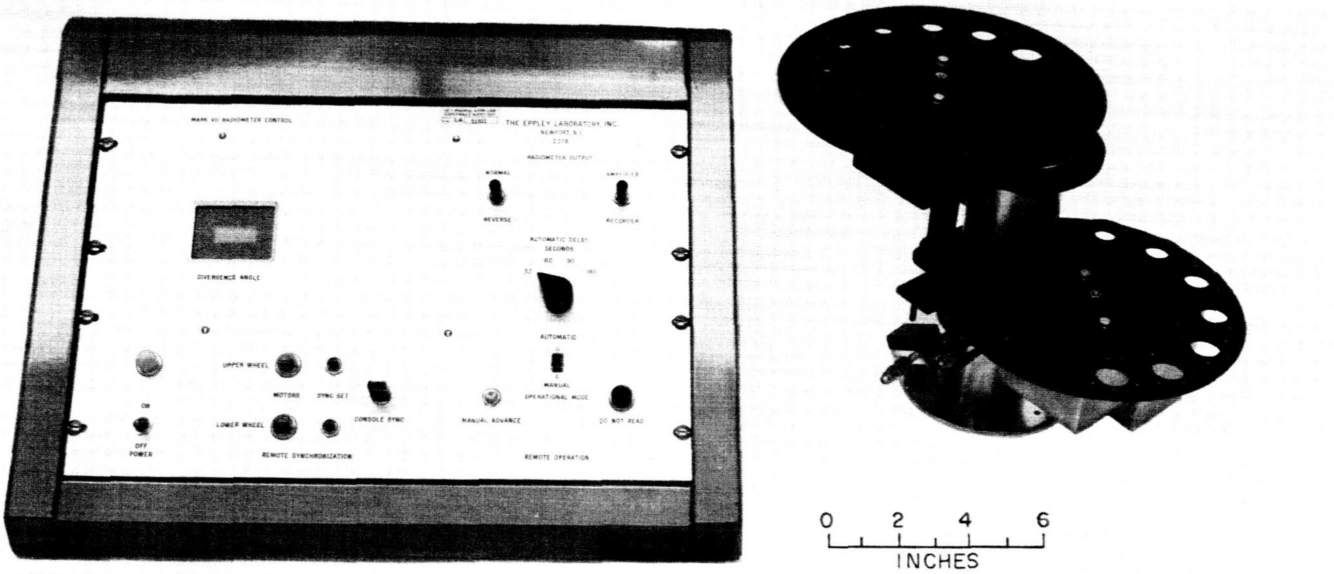


Fig. 21. Eppley Mark VII radiometer for measuring light beam divergence

Response time to 98% of steady-state value is 3 and 10 sec for air and vacuum, respectively.[3]

The Eppley Mark VII radiometer (Fig. 21) employs remotely positioned aperture discs in order to determine light beam divergence over a range of 2 to 20 deg total angle.

The Eppley Mark IV filter radiometer was used as described in Part III during the Eppley spectral determination tests. These tests employed monochrometers, and resulted in an accurate determination of the light beam spectrum in the 25-ft space simulator. The filter radiometer is now used to periodically verify that the spectrum has not changed. Since this technique is not foolproof, monochrometer measurements are occasionally required.

B. *Temperature Measurements*[4]

The following equipment is available for temperature measurements.

1. Thermocouple transducers

Capacity:	400 data channels
Thermocouple types:	Chromel Constantan Copper Constantan
Temperature range:	−300 to +1800°F

2. Resistance temperature sensors

Capacity:	12 channels of excitation

C. *Pressure Measurements*[4]

1. One Atmosphere to 10^{-3} Torr

Launch pressure profiles are measured and recorded by two Baratron measuring systems. Each system consists of two measuring heads. One head ranges from 0 to 10^{3} torr full scale, and the other ranges to 10 torr full scale. With the 10-torr head, it is possible to measure pressures down to 10^{-3} torr.

2. Pressures Below 10^{-3} Torr

Varian ion gage systems are used for vacuum measurements below 10^{-3} torr. The ion gages are mounted close to the test item, and redundant gages are used in case of gage or controller failure.

[3]Additional data is available from JPL or from Eppley Laboratory, Inc.

[4]The equipment listed here is presently available for the 25-ft space simulator; similar equipment will be available for the 10-ft space simulator after the facility construction is complete.

D. *Miscellaneous Instrumentation*[4]

1. Channels into the space simulator are available for miscellaneous voltage measurements.

2. Cabling for the operation of electrical equipment inside the space simulator is available from the recording area.

3. There are 100 channels of 300-w max, 0–120-vac control lines for the operation of heaters or lights inside the space simulator. Fifty of these circuits are connected through watt transducers for measuring power.

[4]The equipment listed here is presently available for the 25-ft space simulator; similar equipment will be available for the 10-ft space simulator after the facility construction is complete.

VI. DATA HANDLING

All transducer outputs appear in analog form at the patchboard in the recording area (Fig. 22). The data are channeled through the appropriate signal-conditioning equipment and are either recorded in analog form or converted to digital data and then recorded. The complete record of a test can be stored on magnetic tape. This tape can be processed on the IBM 7094 computer, and selected parameters can be plotted. The data handling capability of the space simulator facility is described in detail in Table 3.

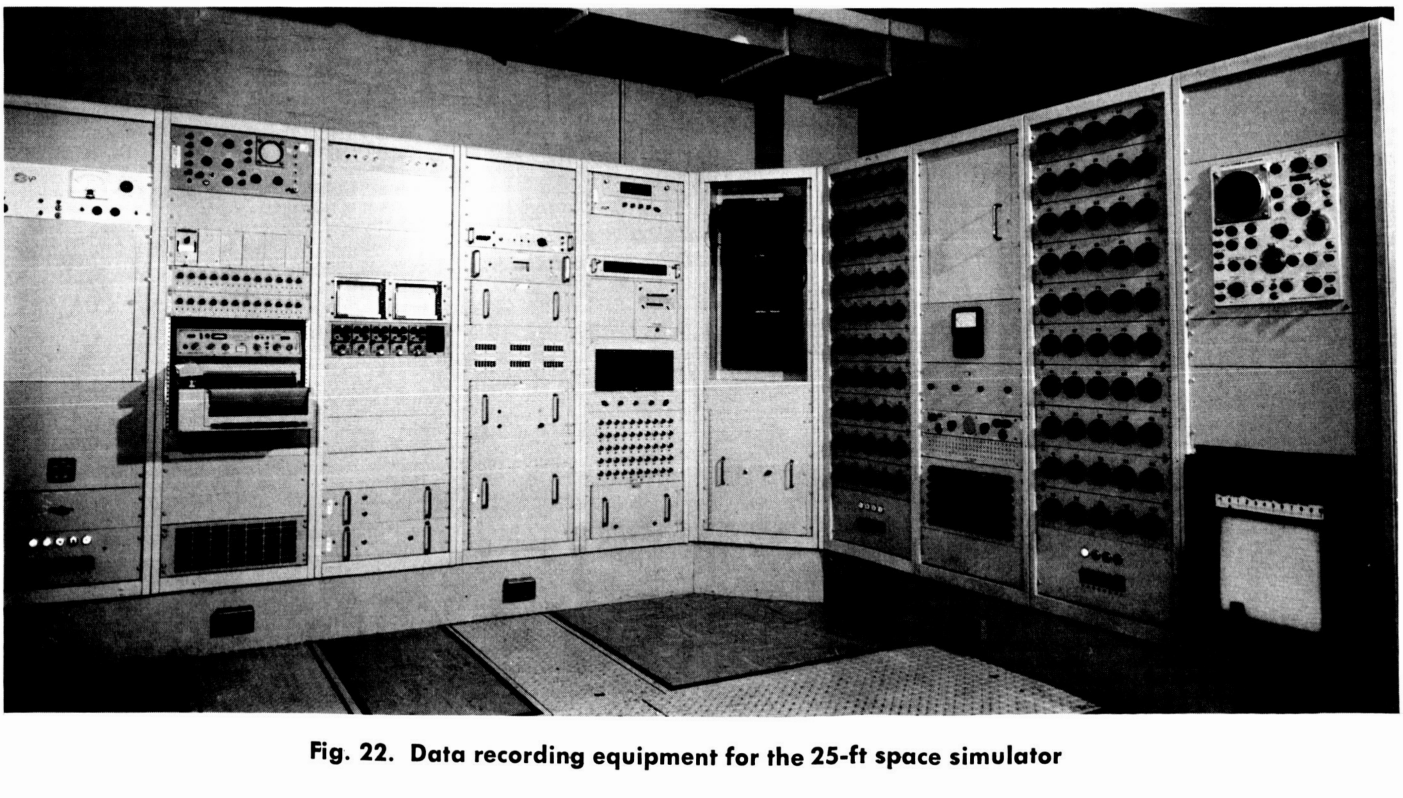


Fig. 22. Data recording equipment for the 25-ft space simulator

Table 3. Data handling capability

Digital recorders		Analog recorders
Datex Data Logger (Fig. 22)		Strip Charts
Channel capacity	200 channels	Both 6-in. and 10-in. strip charts are available for the continuous recording of test parameters.
Voltage input	±10 mv	
Scanning rate	2 channels/sec	Oscillograph
Thermocouple type	Chromel Constantan, referenced to 32°F	A direct-writing oscillograph with 24 channels is available for analog recording.
Temperature ranges	±300°F +200 to +1800°F	Magnetic Tape
Output	Printed paper tape in mv or in °F, as shown in Fig. 23.	A portable magnetic tape unit is available, when required, for recording 14 channels of data.
PDP-4 Computer[a]		Strain Gage Controls
Capacity	400 channels	There are 12 channels of strain gage controls terminating inside the 25-ft space simulator. These controls may also be used for resistance-type temperature sensors.
Voltage input	±10 mv	
Scanning rate	50 channels/sec, max	
Thermocouple types	Chromel Constantan Copper Constantan	
Output	Edited listing on printer at test site	

[a]In Central Recording Service, remote from space simulator.

	TIME	CHANNEL IDENTIFICATION	DATA IN °F
1	8 3 0	2 1 0	0 0 6 6
1	8 3 0	2 0 9	0 0 6 7
1	8 3 0	2 0 8	0 0 7 0
1	8 3 0	2 0 7	0 0 6 8
1	8 3 0	2 0 6	0 0 7 1
1	8 3 0	2 0 5	0 0 7 2
1	8 3 0	2 0 4	0 0 7 1
1	8 3 0	2 0 3	0 0 7 1
1	8 3 0	2 0 2	0 0 6 9
1	8 3 0	2 0 1	0 0 6 9
1	8 3 0	1 5 0	0 0 1 0
1	8 3 0	1 4 9	0 0 1 0
1	8 3 0	1 4 8	0 0 1 0
1	8 3 0	1 4 7	0 0 1 0
1	8 3 0	1 4 6	0 0 0 9
1	8 3 0	1 4 5	0 0 0 9
1	8 3 0	1 4 4	0 0 0 9

Fig. 23. Paper tape output from the Datex digital data recorder

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[5]Eppley Laboratory, Inc.