THE UNIVERSITY OF MICHIGAN

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HIGH ALTITUDE RADIATION MEASUREMENTS

1 January 1968 - 31 March 1968

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Abstract

This report is a summary of project activities during the period 1 January 1968 to 31 March 1968. Gondola equipment testing, including an environmental test, in preparation for the next balloon flight, spectrophotometer linearity checks, and details of the method used for transformation between geographical and Bond albedo coordinate systems are described. Reports and papers published on this and associated contracts are listed.

I. Introduction

This is the 21st quarterly progress report on contract no. NASr-54(03), covering the period 1 January 1968 to 31 March 1968. The project effort during this time was divided among the following tasks:

1. Preparations for the next balloon flight.
2. Laboratory measurements of CO_2 transmission
3. Theoretical study of earth's Albedo
4. Report writing

On January 18, 1968 a meeting was held at Goddard Space Flight Center to discuss progress in the research program. The repeated delay and rescheduling of the balloon flight due to the change in estimated delivery date of the IRIS instrument from the Texas Insturment Company was discussed. The uncertainty introduced results in considerable inefficiency in the operations and increases the cost of this portion of the program. Inasmuch as the work on the IRIS flight instruments (for use on the NIMBUS III Satellite) has greatest priority, there does not appear to be any solution to this problem. It was decided that at best we could try to make certain that all of the balloon flight instrumentation was ready for the flight so that when the IRIS is available, the flight can be carried out without delay. To this end it was decided that an environmental test of all available equipment should be carried out as soon as possible so that any equipment problems could be discovered and corrected.

II. Preparations for the Next Balloon Flight - Gondola Testing.

A. Operations Before Initial Tests.

The IRIS blackbody and door apparatus was built as a separate module which will be attached to the shroud of the IRIS instrument when it is received. The assembly of this unit was completed. The temperature control unit for the blackbody was tested on the gondola.

Conversion factors for telemetered housekeeping voltages were measured.

The alignment of the photocell azimuth measuring device was carried out with the use of the LS-32 Helium Neon gas laser.

The miscellaneous control box was rebuilt. Radiofrequency interference suppression devices, and more reliable door control devices were installed.

The crystal oscillator used as the master clock for timing all operations on the gondola was received and found to operate satisfactorily.

B. Initial Gondola Tests.

1. Tests of Components.

An extensive series of tests was run on the master programmer and on the electromechanical devices operated by it. Some malfunctions of the programmer due to R. F. interference were noticed and corrected by additional shielding of cables.

Next, the U. of M. interferometer was mounted on the gondola and a series of tests were made to determine that mechanical and R. F. noise levels induced by other gondola equipment was within allowable limits. It appears that noise levels are lower than they were on the last balloon flight.

After this, all available instruments were mounted on the gondola and individual units were tested for normal operation.

2. First Gondola Test (February 16).

The first operational gondola test of all available equipment was run without cooling the U. of M. Interferometer to its normal operating temperature of 0°C.

The following problems were encountered:

(a) Number 2 calibrate voltage supply (0-5v) failed.

(b) Photocell drive shaft was slipping. Set screws were too small.

(c) Filter wedge door system did not operate.

(d) Maurer camera no. 1 failed to operate. The delay release ID 8 had failed due to a low reed relay coil resistance.

(e) There was a loss of synchronism between the U. of M. interferometer and the Maurer cameras due to interference by ground check out controls used with the interferometer. They will not be used for any full scale system tests or during flight.

(f) Spin jets failed to operate at the first time pulse but otherwise operated properly.

(g) Number 9 discriminator lost signal due to overheating

(h) No signals were transmitted on channels B and 13. This was due to a defective strip chart recorder switch, a VCO installed in a wrong socket and a missing cable connection.

(i) The PDP 8 computer operated intermittantly.

(j) The time required for cooling the U. of M. interferometer to its operating temperature was much too long. It was found that the cooling coil had separated from the instrument base.

(k) At times the interferometer signals were quite noisy due to R. F. interference caused by various D. C. motors. Filter capacitors were placed on these motors.

Some of these problems were corrected during the next few days and preparations were made for the second gondola test.

3. Second Gondola Test (February 20).

This test was run with the U. of M. interferometer cooled to its proper operating temperature. Some problems that had been discovered on the first gondola test had not been corrected and some apparatus for use with instruments not yet available was not yet complete, however the test was run to uncover other problems that might exist. Several new problems were discovered.

(a) The U. of M. interferometer data was noisy due to the fact that the power stage of the new mirror drive amplifier had been incorrectly connected to the low capacity regulated supply. This was corrected.

(b) There was cross talk between the channels of a Brush recorder.

C. Preparations for Environmental Test.

Although it had been determined that camera vibrations would not interfere with the interferometer as long as the programmers maintain synchronism, interference would be considerable upon loss of synchronism. To decrease the noise in this event, the Maurer cameras and the T. I. IRIS blackbody and door assembly were shock mounted.

All other problems noted above were corrected and another "cold" test of the balloon gondola was run on March 5. This test indicated satisfactory operation of all instruments and so the equipment was removed from the gondola and packed for the trip to the Bendix Mishawaka (Indiana) Division.

A pseudo filter wedge spectrometer package dissipating 35 watts was constructed so that information on probable filter wedge temperatures could be obtained during the test.

D. Environmental Test

On March 11, laboratory personnel left for the Bendix Mishawaka Division. The equipment was unloaded after arrival on the same day. The gondola was reassembled and a preliminary "cold test" was run on the 12th. The gondola is shown in the chamber during preparations in figures 1 and 2, looking into and out of the chamber, respectively.

The environmental test was run on 13 March, starting at 1130 EST and ending at 1823 EST. Curves of chamber temperature vs. time are shown in figure 3. Data obtained by Bendix personnel with thermocouples at 2 locations in the chamber are compared with temperatures measured by the free air temperature thermistors on the gondola. Chamber pressure vs. time are shown in figure 4.

Temperatures measured at many points on the gondola during the test are shown in figures 5 and 6. Housekeeping data for the MRIR are shown in figure 7.

The overall results of the test were satisfactory. Problems encountered during the test are listed in table I.

E. Changes Made After the Environmental Test

Repairs have been made to correct each of the problems encountered during the test.

Several housekeeping functions have been added to the list of functions monitored during the flight. These are:

1. Additional battery monitors
    a) IRIS time code generator: -10V., +10V., -24V.
    b) T. I. IRIS blackbody temperature control battery
    c) T. I. IRIS and U. M. interferometer -24V. batteries
2. U. M. interferometer cold blackbody temperature.
3. The Maurer camera pulses will be monitored on the interferometer magnetic tape recorder.

The temperature data obtained during the environmental test for the simulated filter wedge instrument indicated that cooling may be required during the flight. Thus a liquid nitrogen cooling system has been designed for this instrument. This cooling system will operate whenever the base plate of the filter wedge frame is above 10°C. To avoid trapping frost on the cooling coils, the system will not operate below 25000 feet. To counteract possible baro-switch failure, its operation will be overruled by timer.

TABLE I PROBLEMS AT BENDIX ENVIRONMENTAL TEST 3-13-68

Problem	Cause
1. FAT barometric switch circuit.	1. Open circuit on ground side of baroswitch.
2. Photocell motor burned out.	2. To be investigated by factory (burned out motor inverter).
3. Maurer heater circuit #1 apparently did not operate.	3. No definite conclusions (thermostat stuck in closed position?)
4. MRIR heater circuit did not operate.	4. Improperly wired heater microswitch.
5. FAT temperature fluctuation.	5. PDP8 program (data has been corrected).
6. Temp effects on UM IRIS drive - loss of digitizing pulses.	6. Cold solder joint - (has been repaired).
7. Crosstalk on Brush recorder.	7. Low line voltage.
8. TI blackbody temperature control circuit (heating power).	8. Inadequate heating capacity at low temp(-50°C)
9. Pressure altitude clock did not operate.	9. Left unwound for too long a time.
10. Time code generator (minute counter) malfunction.	10. #4 code added wherever #2 code appears.

The program of operation of the U. of M. interferometer has been modified. A moveable view mirror will be placed under the interferometer so that measurements of sky radiation as well as earth radiation can be obtained. The sequence of 16 interferograms which make up one data cycle will be as follows:

a) 2 of the cold blackbody
b) 2 of the warm blackbody
c) 4 of the earth scene
d) 2 viewing horizontally
e) 2 viewing 22° above the horizon
f) 2 viewing 44° above the horizon
g) 2 mirror calibrate position (to determine the effect of the mirror)

The electromechanical apparatus is being constructed and the IRIS programming modifications for this change are being made.

F. Additional Work Done in Preparation for the Balloon Flight.

The interferometer data processing effort has been devoted to programming for the calculation of spectra from a one sided interferogram.

Because of the changes described above, the schematic electrical circuit diagrams have been modified.

A second flight unit for our preliminary balloon flight check of telemetry has been completed. A test run has been made with associated battery failure due to the use of Mercury cells which had exceeded their shelf life.

The quality of telemetry tape recordings has been improved by reducing the tape speed compensation frequency from 100 Khz. to 50 Khz. Tape speed used is 15 inches per second. At this speed the recording of the 100 Khz. signal was often marginal with associated poor tape speed compensation.

New procedures have been adopted for testing of Mercury batteries. A substantial number of new cells has been ordered directly from the factory to avoid the degradation due to time spent on the shelf at the distributor.

III. Laboratory Measurements of CO_2 Transmission (by Henry Reichle).

Most of this period was spent attempting to obtain an accurate calibration of the spectrophotometer transmissivity scale. A satisfactory calibration was achieved by two independent methods. In the first, three metal screens (figure 8), which had been optically blackened, were calibrated at the Goddard Space Flight Center on a Cary Model 90 Spectrophotometer. In the second, flat circular disks (figure 9) with open segments of known dimension were rotated at high speed in the sample beam. By using disks with different open areas it was possible to check the linearity at several different values of transmissivity.

The results of this calibration are shown in table II. The agreement between the two methods was good, i.e., better than 1%, as can be seen by inspection of the data.

It was originally expected that spectrometer data would be obtained during this period, however, because of a pressure gage failure this was not possible. Return of this gage from the factory is expected during the first week of April and it is expected that data will be obtained at that time.

IV. Theoretical Study of Earth's Albedo.

A. Coordinate Transformation Associated with Earth Albedo Calculations.

The problem of coordinate transformation referred to arises in connection with the comparison of values of earth's albedo calculated by two different methods:

1. The precise definition of earth's albedo.
2. Values of earth's albedo obtained using a Danjon type of experiment with the Bond definition of Albedo.

Briefly, for the precise albedo, the coordinates of a point Q on the earth sphere are given by geographical longitude and co-latitude (ξ', η'), whereas in the Bond definition of albedo, the longitude and co-latitude (ξ, η) used for the point Q are defined relative to a great circle determined by the plane OES containing the center of the earth O, the sub-solar point S and the sub-observor point E. For a given point Q it is necessary to determine the values of (ξ, η) corresponding to sets of values of (ξ', η') and vice versa.

TABLE II LINEARITY CHECK

Perkin Elmer Model 221 Spectrophotometer

KBr. Prism

Slit 710 2X

Date 3-22-68

Att. 8

Spd. 24

.050	.05	.052	.052	.053	.053	.056	.057	.058	.058
.092*	.081	.083	.083	.083	.082	.083	.082	.082	.082
.100	.10	.102	.105	.108	.108	.110	.111	.111	.112
.158*	.142	.143	.143	.142	.141	.141	.141	.141	.141
.200	.202	.202	.203	.205	.207	.210	.211	.211	.212
.400	.396	.397	.400	.403	.407	.408	.408	.409	.409
.600	.598	.598	.600	.603	.606	.605	.608	.608	.608
.800	.800	.800	.800	.806	.804	.802	.805	.806	.806
.861*	.863	.862	.862	.861	.854	.851	.851	.851	.851
.900	.898	.898	.900	.902	.899	.898	.900	.900	.901
.950	.948	.947	.947	.950	.948	.945	.948	.946	.947

Note: Data was obtained with the wire screen method in those cases indicated by an asterisk, the flat rotating circular disk was used for the rest of the calibration data.

The previous progress report[1] has discussed a possible method of making this transformation, however a large number of sets of equations were used. Computer implementation would have been complicated and cumbersome and so the problem has been re-examined. A detailed description of the problem and of a more straightforward method of solution follows.

B. Coordinate systems Used in Albedo Calculations[2]

1. Coordinates used for a description of reflectance and scattering processes are:

θ_0 = the zenith angle of the incident ray

ϕ_0 = azimuth of incident ray extended (measured counter clockwise from north as viewed from above).

θ = the zenith angle of the reflected or scattered ray

ϕ = azimuth of reflected or scattered ray (measured counter clockwise from north as viewed from above).

$\psi = \phi - \phi_0$

β = scattering angle, where:

$\cos\beta = \sin\theta_0 \sin\theta \cos\psi - \cos\theta_0 \cos\theta$

2. Coordinates used for precise earth's albedo calculations (for integration over the sunlit portion of the earth) are:

θ_0 = zenith angle of the sun

ϕ_0' = azimuth of a point Q on the surface of the earth relative to the sub-solar point, measured counter clockwise from north as viewed from above.

3. Geographical coordinates of a point Q on the earth, are:

ζ' = its longitude measured westward from the Greenwich meridian

η' = its colatitude measured from the north pole

4. Coordinates of the sun are given as:

δ_s = its declination relative to the equator

h_s = its hour angle relative to the point Q

5. Coordinates used for Bond Albedo calculations are:

ζ = longitude, measured in the plane OES determined by the center of the earth O, the subsolar point S and the sub observor point E measured in the counter clockwise direction as viewed from P (see below)

η = colatitude, measured from the pole P which lies in the direction of the vector product OExOS.

α = the phase angle is the value of corresponding to the arc OS

Figure 10 illustrates the use of these various coordinate systems.

C. Celestial Coordinate Systems.

The problem of transformation from the geographical (terrestial) coordinates (ξ', η') to the Bond Albedo coordinates (ξ, η) and vice versa is similar to the problem of transformations between equatorial and ecliptic coordinates used in astronomy (see figure 11). The solution to the latter problem indicates how we can proceed to solve our problem.

The coordinates used in the equatorial system are right ascension α and declination δ. Right ascension is measured by the arc of the equator eastward from the reference point (the First Point of Aries ♈) to the meridian circle of the given point. The First Point of Aries or vernal equinox is that intersection of the ecliptic with the equator at which the sun in its apparent annual motion crosses the equator from south to north. Declination is measured as defined in section B above.

The coordinates of a point in the ecliptic system are celestial longitude λ and celestial latitude β. Celestial longitude is measured eastward along the ecliptic from the First Point of Aries to the circle of celestial latitude through the given point. Celestial latitude is the angular distance from the ecliptic measured along the latitude circle through the point, positive to the north and negative southward.

The fundamental relations for conversions between these two systems are obtained from the trigonometric relations between the parts of the spherical triangle EPS shown in figure 11. In this triangle the three sides are $90^\circ - \beta$ opposite the angle $90^\circ + \alpha$, $90^\circ - \delta$ opposite the angle $90^\circ - \lambda$, and the arc joining the two poles E and P which is equal to the angle ε, the obliquity of the ecliptic. The relations are:

$$\begin{aligned}
\sin\beta &= \cos\varepsilon \sin\delta - \sin\varepsilon \cos\delta \sin\alpha, \\
\cos\beta \sin\lambda &= \sin\varepsilon \sin\delta + \cos\varepsilon \cos\delta \sin\alpha, \\
\cos\beta \cos\lambda &= \cos\delta \cos\alpha; \\
\sin\delta &= \cos\varepsilon \sin\beta + \sin\varepsilon \cos\beta \sin\lambda, \\
\cos\delta \sin\alpha &= \cos\varepsilon \cos\beta \sin\lambda - \sin\varepsilon \sin\beta, \\
\cos\delta \cos\alpha &= \cos\beta \cos\lambda.
\end{aligned}$$

Either transformation may be derived from the other by interchanging λ with α, and β with δ, and changing ε to $-\varepsilon$.

The angle η'' opposite the side ε may be obtained from

$$\cos\beta\cos\eta'' = \cos\varepsilon\cos\delta + \sin\varepsilon\sin\delta\sin\alpha,$$
$$\cos\beta\sin\eta'' = \sin\varepsilon\cos\alpha;$$
$$\cos\delta\cos\eta'' = \cos\varepsilon\cos\beta - \sin\varepsilon\sin\beta\sin\lambda,$$
$$\cos\delta\sin\eta'' = \sin\varepsilon\cos\lambda.$$

This set of transformations can be applied to our problem if on addition we provide:

1) The transformation between the geographical coordinates (ζ', η') and the equatorial coordinates (α, δ)

2) The transformation between the Bond albedo coordinates (ζ, η) and the ecliptic coordinates (λ, β)

3) Calculate the angle of obliquity ε between the fundamental circles of the geographical and Bond Albedo coordinate systems

This information is contained in the next section, where the solution to our problem is described explicity.

D. The Transformation Between (ζ', η') and (ζ, η)

Following the procedure outlined above, we find:

$$\zeta' = \zeta'_r - \alpha \qquad \eta' = 90 - \delta$$

or

$$\alpha = \zeta'_r - \zeta' \qquad \delta = 90 - \eta'$$

where ζ'_r is the geographical coordinate of the intersection of the fundamental circles of the Bond Albedo coordinate system with the equator, which is the 1st intersection obtained when moving in the direction E to S.

Also, if (ζ'_p, η'_p) are the geographical coordinates of the pole of the Bond Albedo coordinate system, then:

$$\varepsilon = \eta'_p$$

and

$$\zeta'_r = \zeta'_p - 90$$

where

$$\zeta'_p = \zeta'_E - (\Delta\zeta' + 90^\circ) \text{ when } \delta_E > 0,\ \delta_E > \delta_S$$
$$\zeta'_p = \zeta'_E + (\Delta\zeta' + 90^\circ) \text{ when } \delta_E > 0,\ \delta_E < \delta_S$$
$$\zeta'_p = \zeta'_E - (\Delta\zeta' - 90^\circ) \text{ when } \delta_E < 0,\ \delta_E < \delta_S$$
$$\zeta'_p = \zeta'_E + (\Delta\zeta' - 90^\circ) \text{ when } \delta_E < 0,\ \delta_E > \delta_S$$

where $\Delta\zeta' = |\zeta'_E - \zeta'_r|$ can be obtained from

$$\sin\Delta\zeta' = \frac{\sin\delta_E\cos\delta_S\sin(h_E - h_S)}{\sin\eta'_p\sin\alpha}$$

and, in turn:

$$\cos \eta_p' = \frac{\cos \delta_E \cos \delta_S \sin (h_E - h_S)}{\sin \alpha}$$

$$\cos \alpha = \sin \delta_E \sin \delta_S + \cos \delta_E \cos \delta_S \cos (h_E - h_S)$$

The transformation between Bond Albedo coordinates and ecliptic coordinates is given by:

$$\zeta = \lambda + \alpha_E \qquad \eta = 90 - \beta$$

or

$$\lambda = \zeta - \alpha_E \qquad \beta = 90 - \eta$$

where $\sin \alpha_E = \dfrac{\sin \delta_E}{\sin \eta_p'}$

Substituting in the relations for transformation from equatorial to ecliptic celestial coordinates we find:

$$\cos \eta = \cos \eta_p' \cos \eta' - \sin \eta_p' \sin \eta' \sin (\zeta_\gamma' - \zeta')$$

$$\sin \eta \sin (\zeta - \alpha_E) = \sin \eta_p' \cos \eta' + \cos \eta_p' \sin \eta' \sin(\zeta_\gamma' - \zeta')$$

$$\cos \eta \cos (\zeta - \alpha_E) = \sin \eta' \cos (\zeta_\gamma' - \zeta')$$

and conversely:

$$\cos \eta' = \cos \eta_p' \cos \eta + \sin \eta_p' \sin \eta' \sin (\zeta - \alpha_E)$$

$$\sin \eta' \sin (\zeta_\gamma' - \zeta') = -\sin \eta_p' \cos \eta + \cos \eta_p' \sin \eta \sin (\zeta - \alpha_E)$$

$$\sin \eta' \cos(\zeta_\gamma' - \zeta') = \sin \eta \cos (\zeta - \alpha_E)$$

Using these relations the procedure to be followed is quite straightforward. Given the coordinates of E and S, that is (ζ'_E, δ_E) or (h_E, δ_E) and (ζ'_S, δ_S) or (h_S, δ_S):

1. Calculate α, η_p', $\Delta\zeta'$ and ζ_p'
2. Then find ζ_γ' and α_E
3. Apply three of the six equations of transformation to go from (ζ', η') to (ζ, η) or vice versa.

V. Report Writing.

Quarterly report 05863-19-P covering the period 1 July 1967 - 30 September 1967 was distributed.

A note submitted in March 1967 has been published: S. R. Drayson and C. Young, Band Strength and Line Half-Width of the 10.4 μ CO_2 Band; J. Quant. Spectrosc. Radiat. Transfer, Vol. 7, pp 993-995, November/December 1967.

Several reports have been published by members of the laboratory staff. Although the work was supported by other agencies, it rests in part on previous work done under this contract. These reports are:

1. S. R. Drayson (E. S. Epstein Project Director) The Calculation of Long-Wave Radiative Transfer in Planetary Atmospheres, Report #07584-1-T University of Michigan, Department of Meteorology and Oceanography, National Science Foundation Grant No. GP-4385, November 1967.
2. S. R. Drayson and C. Young, The Frequencies and Intensities of Carbon Dioxide Absorption Lines Between 12 and 18 Microns, University of Michigan, High Altitude Engineering Laboratory, Department of Aerospace Engineering, ESSA Contract No. Cwb-11376, November 1967.
3. S. R. Drayson, S. Y. Li, and C. Young, Atmospheric Absorption by Carbon Dioxide, Water Vapour and Oxygen, University of Michigan, High Altitude Engineering Laboratory, Department of Aerospace Engineering, ESSA Contract No. Cwb-11376, February 1968.

VI. Future Work

During the next quarter preparations for the next balloon flight will continue (it is not anticipated that the balloon flight will be carried out since delivery of the IRIS interferometer is scheduled for late in the time period). Work on laboratory measurements of CO_2 transmission and on the earth's albedo study will also continue.

It is also planned to initiate a program of upward looking measurements of infrared sky radiation in the 10-11 micron region, using the window channel of the MRIR.

VII. References

1. F. L. Bartman, High Altitude Radiation Measurements, Quarterly Progress Report, 1 October 1967 - 31 December 1967, Report #05863-20-P, The University of Michigan, High Altitude Engineering Laboratory, Department of Aerospace Engineering, May 1968.

2. F. L. Bartman, The Reflectance and Scattering of Solar Radiation by the Earth, Report #05863-11-T, The University of Michigan, High Altitude Engineering Laboratory, Department of Aerospace Engineering, February, 1967.

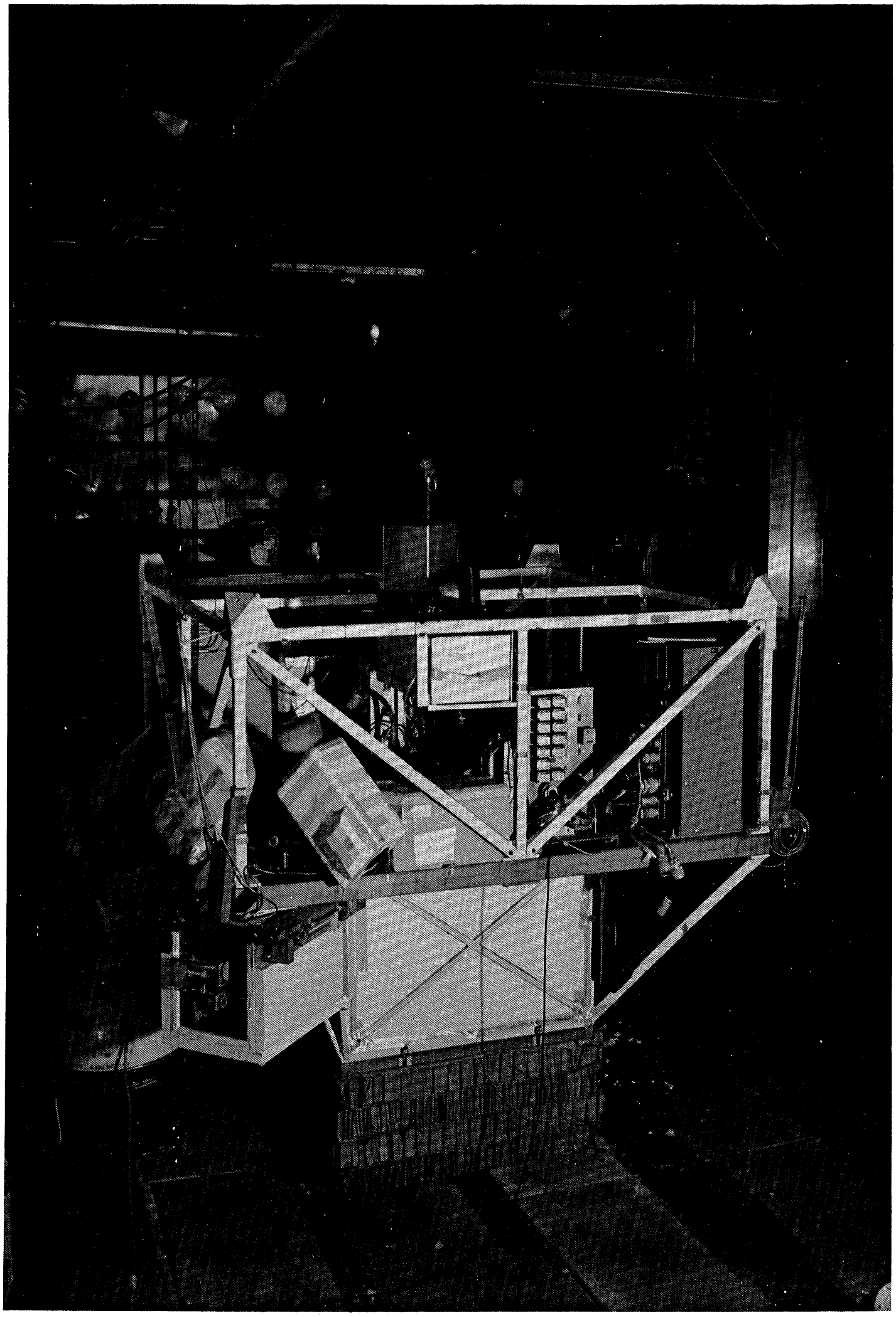

Figure 1. Gondola in environmental test chamber (view into chamber)

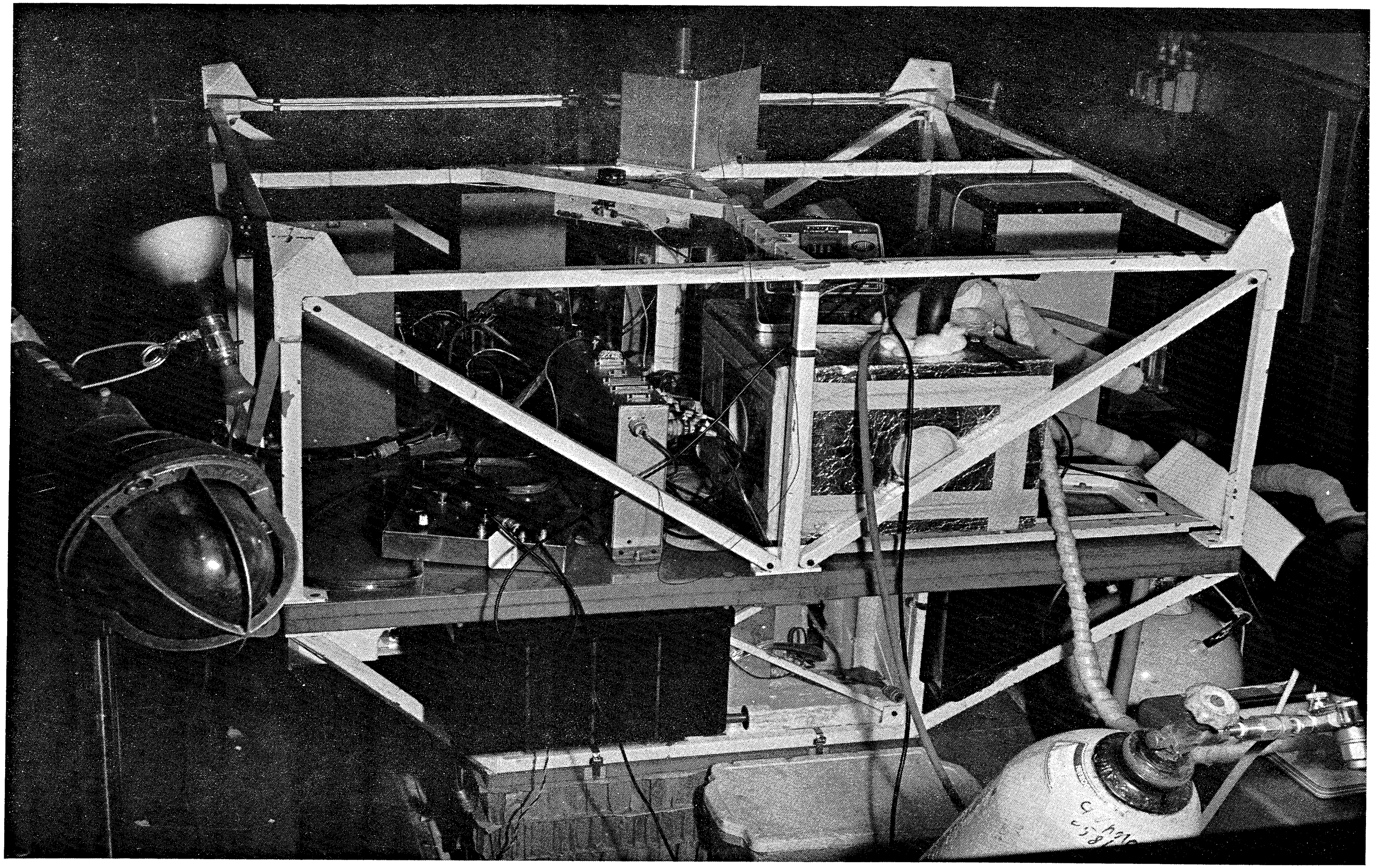

Figure 2. Gondola in environmental test chamber (view out of chamber)

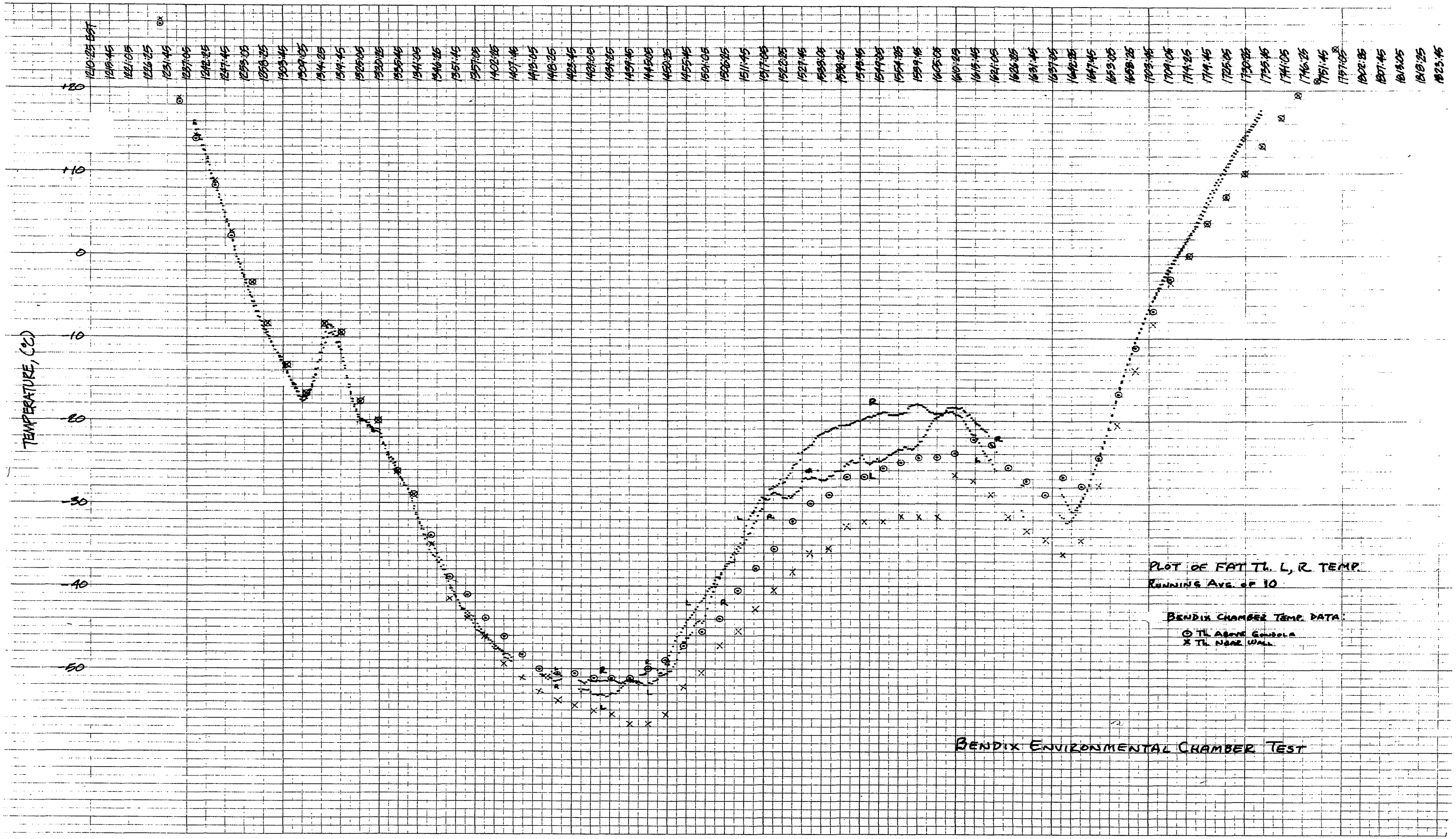

Figure 3. Environmental test chamber temperature vs. time

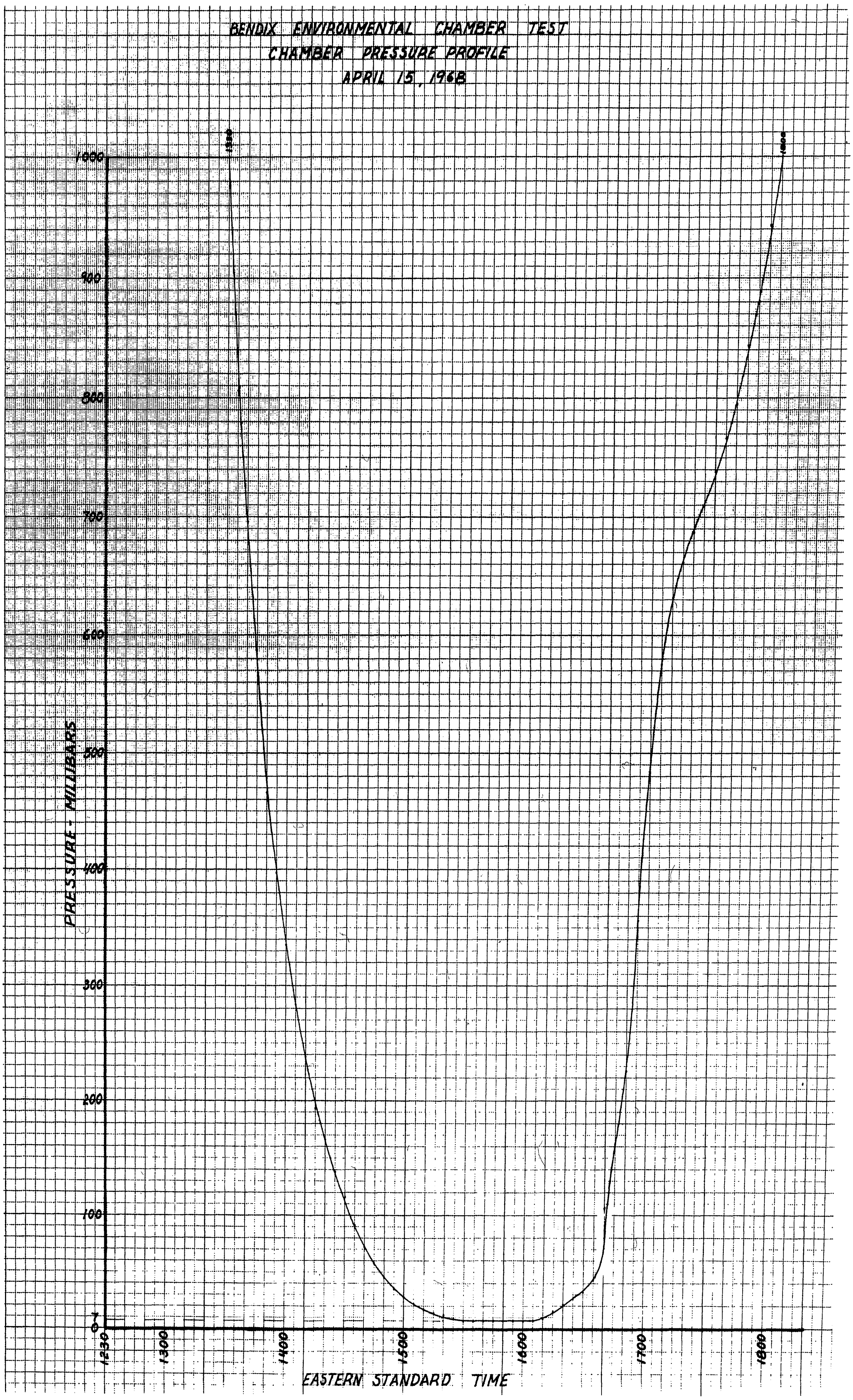

Figure 4. Environmental test chamber pressure vs. time

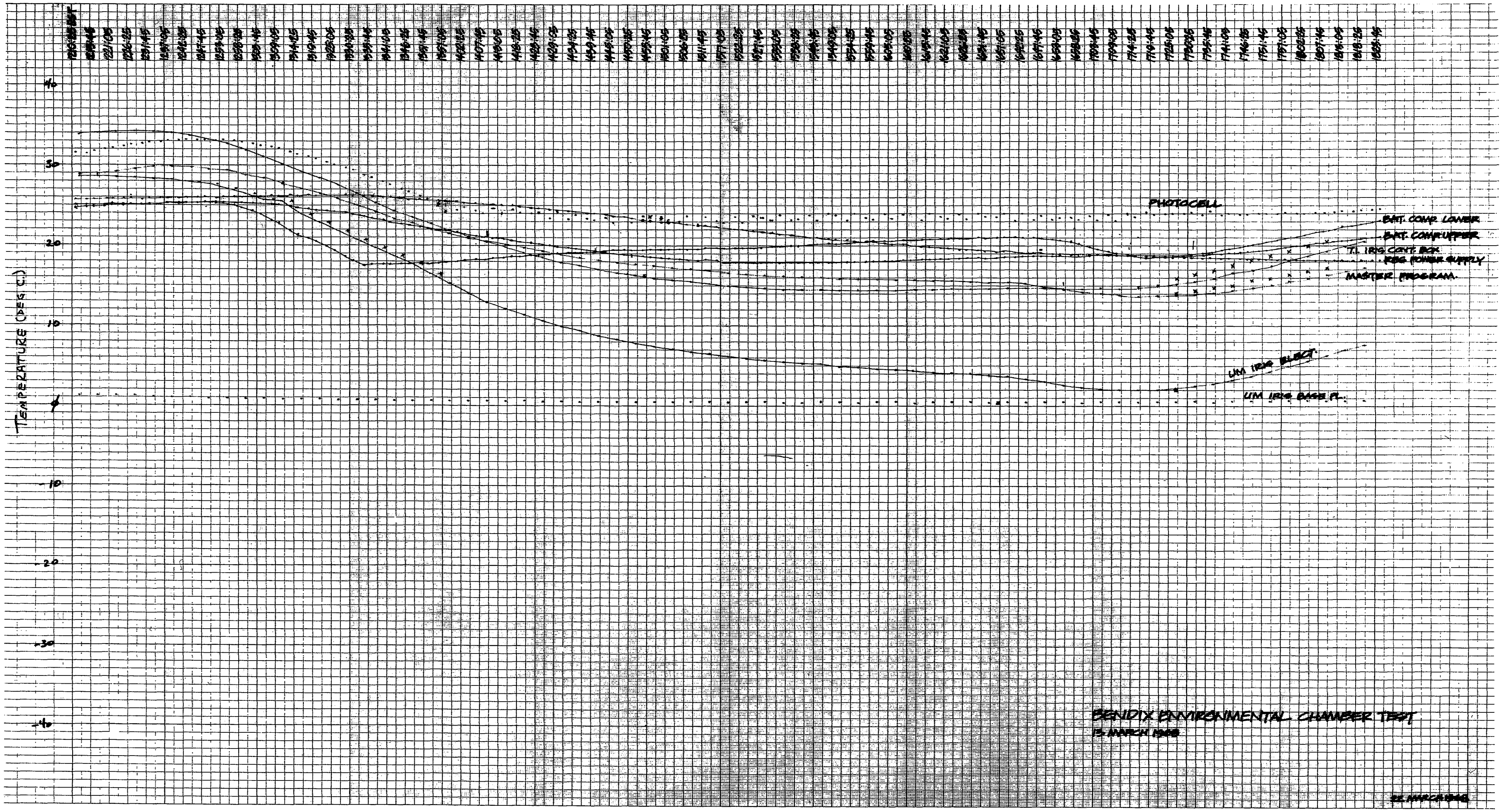

Figure 5. Gondola temperatures during environmental test, I.

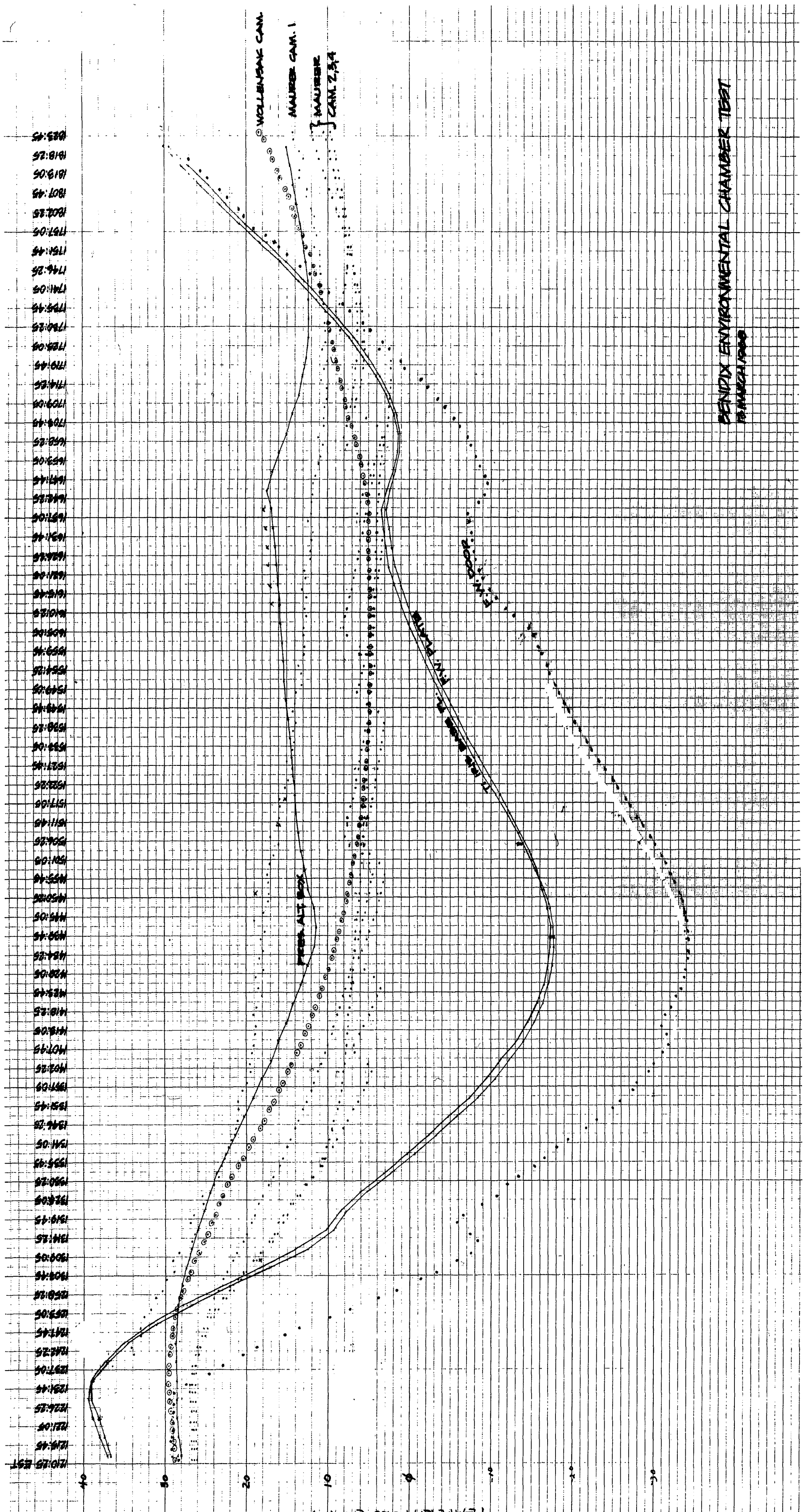

Figure 6. Gondola temperatures during environmental test, II.

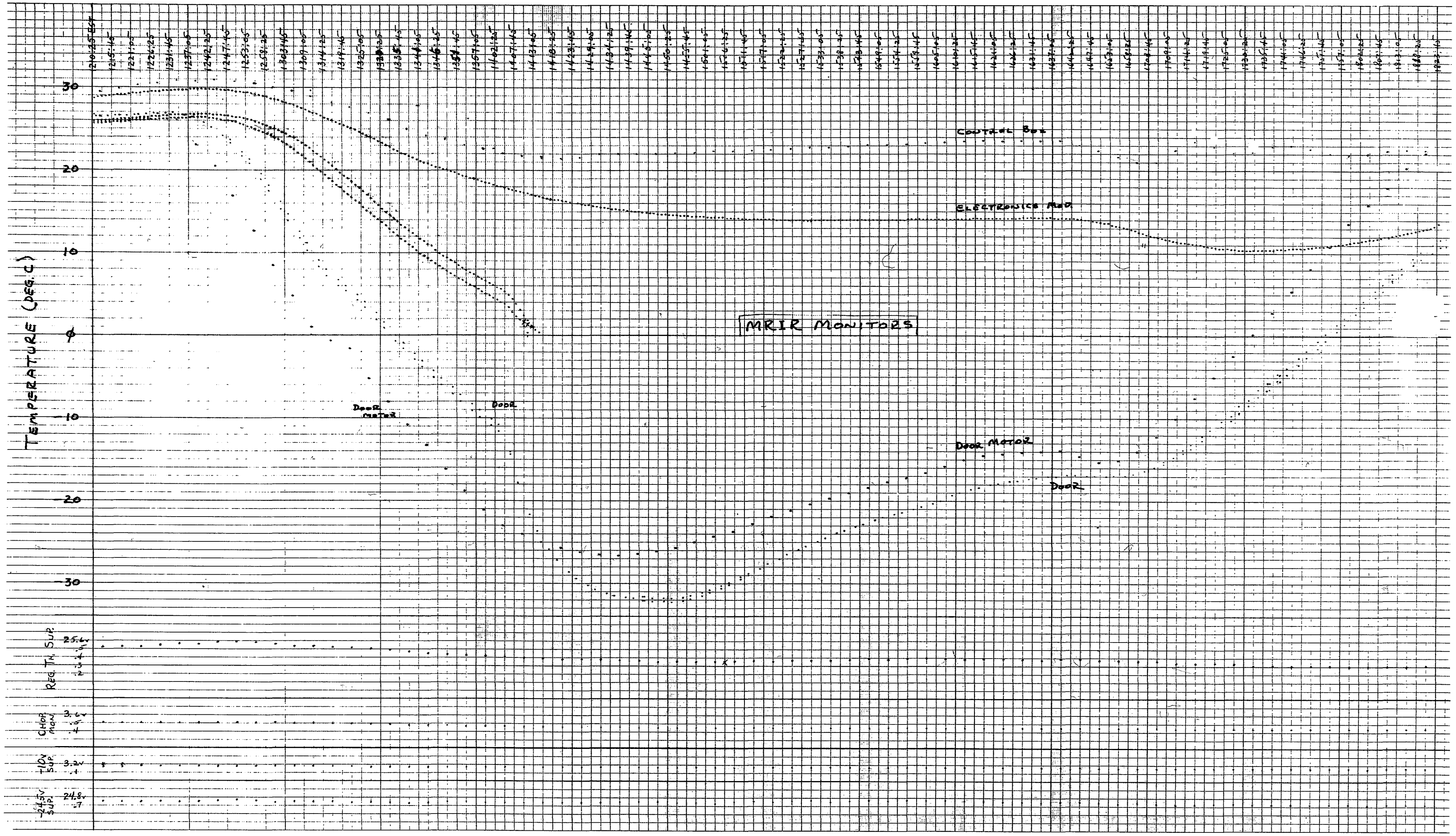

Figure 7. Housekeeping data for MRIR during environmental test.

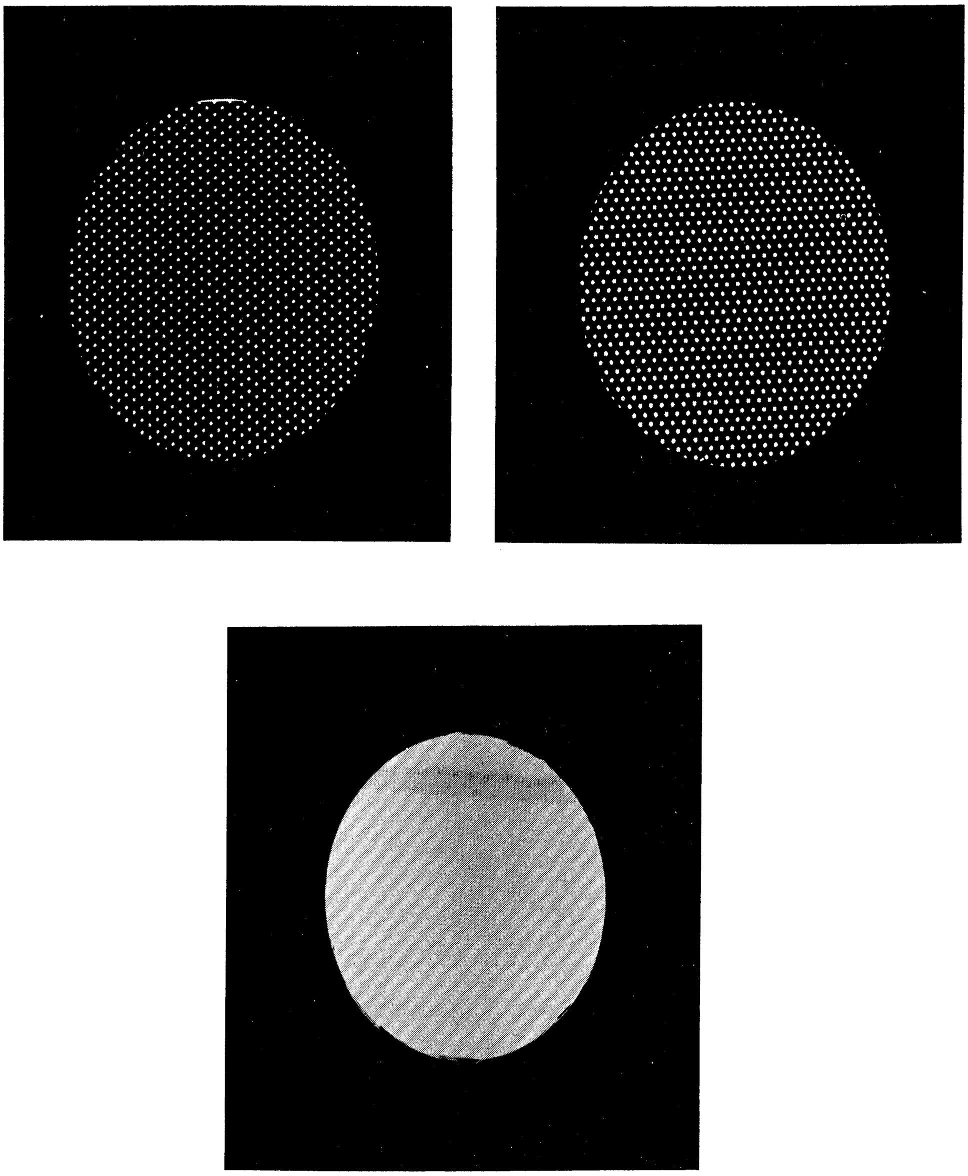

Figure 8 Wire screens used for spectrophotometer calibration

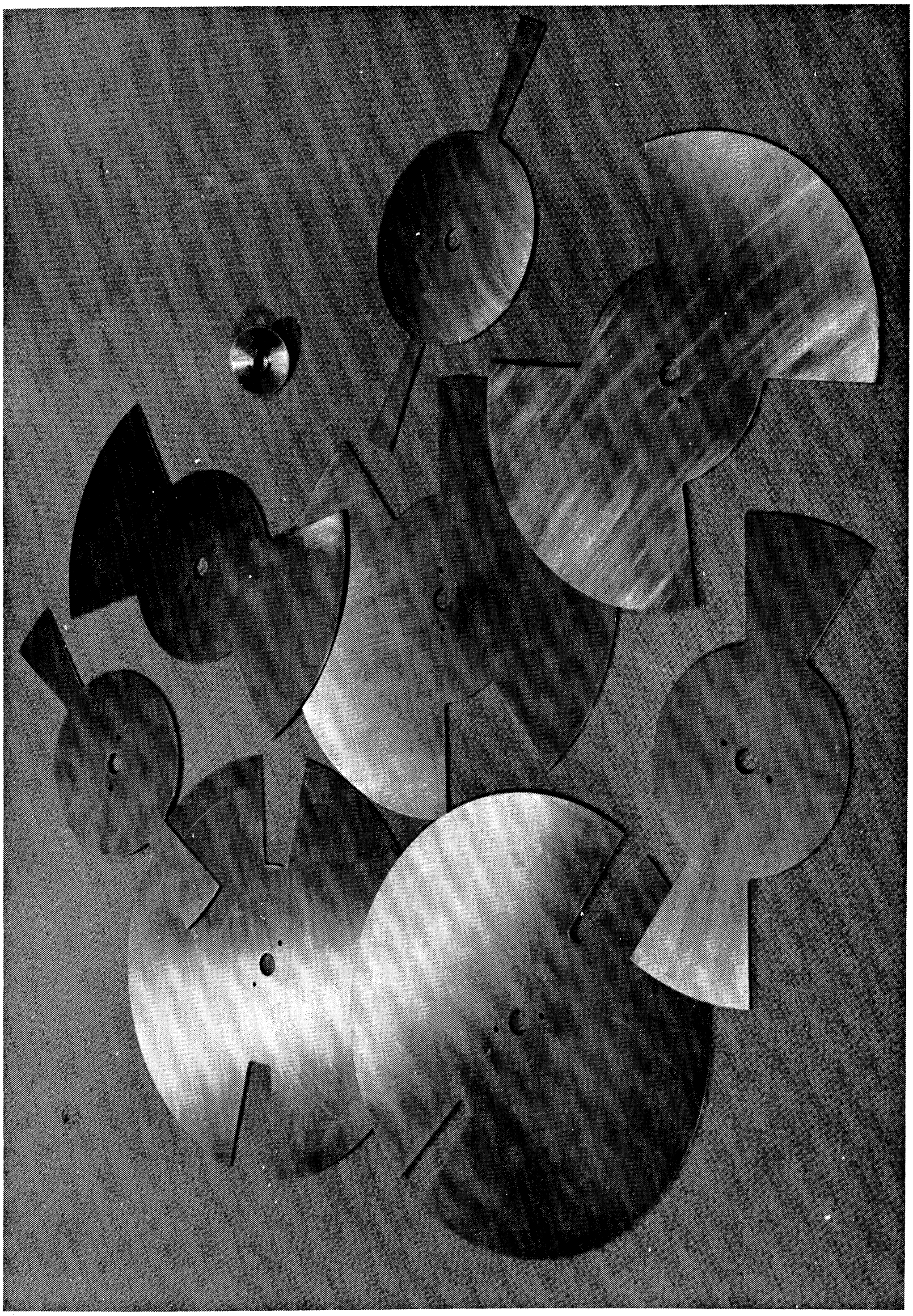

Figure 9. Flat chopper disks used for spectrophotometer calibration.

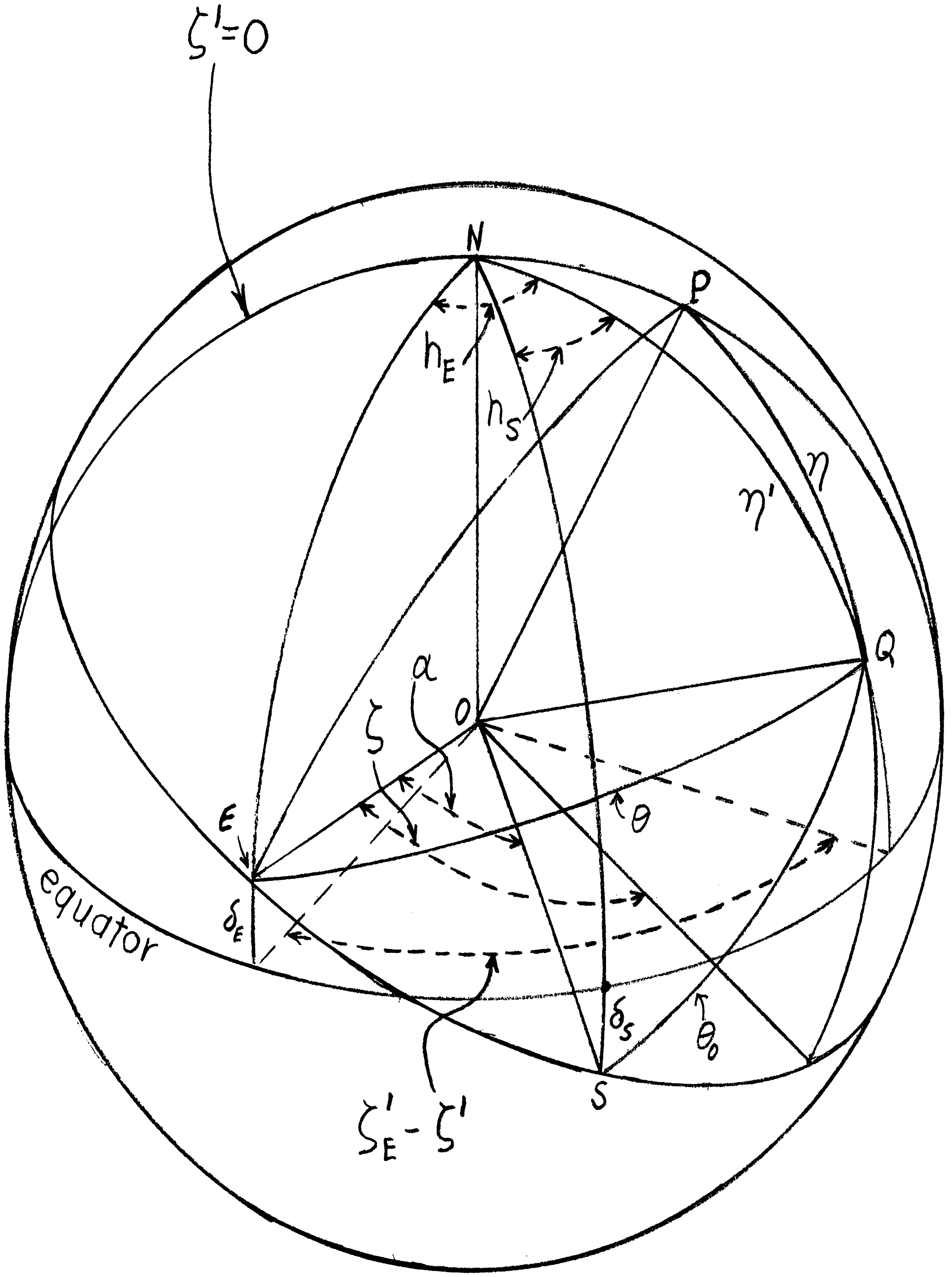

Figure 10. Coordinate systems used for albedo calculations

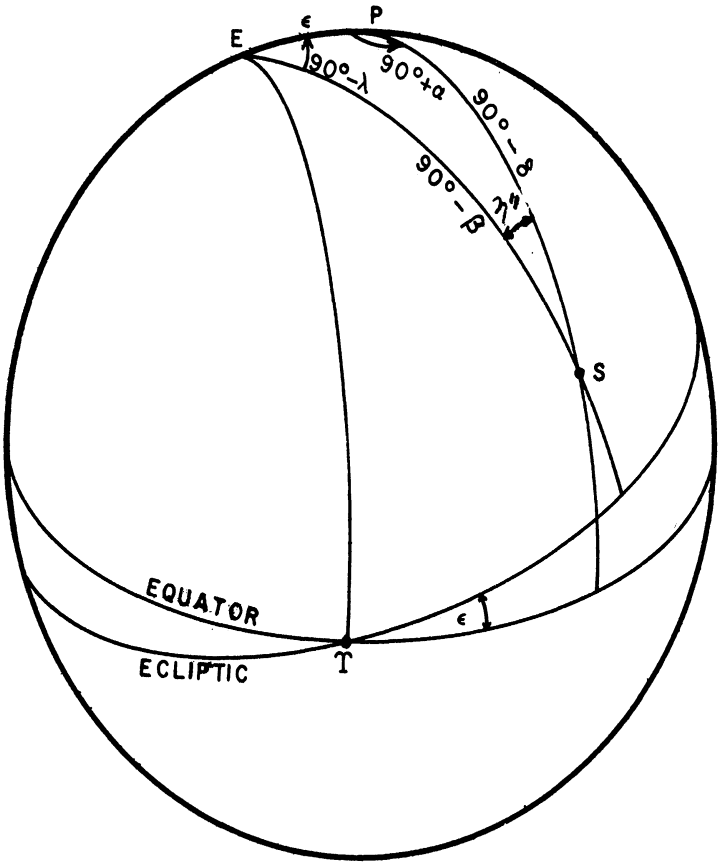

Figure 11. Equatorial and ecliptic celestial coordinate systems.