THE UNIVERSITY OF MICHIGAN

COLLEGE OF ENGINEERING
High Altitude Engineering Laboratory
Departments of
Aerospace Engineering
Meteorology and Oceanography

Quarterly Report

HIGH ALTITUDE RADIATION MEASUREMENTS

1 April 1969 - 30 June 1969

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Abstract

This report summarizes project activity during the period 1 April 1969 to 30 June 1969. Analyses of three sets of data (MRIR measured 0.2-4.0μm earth reflectance, filter wedge spectrometer atmospheric radiance and U. of M. interferometer data) from the 20 November 1968 balloon flight are well along. Laboratory calibrations of the IRIS interferometer have been carried out. High resolution and medium resolution spectrometer measurements of 15μm CO_2 absorption are being carried out. Theoretical studies (atmospheric transmissivities, inversion of atmospheric radiances to 0_3 content and distribution, microwave occultation data analysis) are underway. The need for the study of molecular collision rates (relaxation times) and plans for an improved experiment for improved measurements of such data are described.

I. Introduction

This is the 26th Quarterly Progress Report on Contract No. NASr-54(03) covering the period 1 April to 30 June 1969. The project effort during this period of time was divided among the following tasks.

1. Analysis and processing of data for 20 November 1968 balloon flight.
2. Medium and high resolution measurements of the 15μm absorption band of CO_2.
3. Determination of the vertical distribution of O_3 from radiance measurements in the 9.6μm band.
4. Laboratory tests of the IRIS interferometer.
5. The study of techniques for measuring molecular collision rates.
6. Microwave occultation studies.
7. Report writing.

II. Analysis and Processing of Data for 20 November 1968 Balloon Flight

A. MRIR 0.2-4.0μm Channel Data

Bi-directional reflectance data measured with the 0.2-4.0μm channel of the MRIR have been processed for the entire flight. Data were taken with this instrument for the entire time that the balloon was at altitude, 1050-1530 E.S.T. During this time the balloon flew over the relatively barren surface (in November) south of Rapid City, South Dakota. The sub-balloon point moved from the South Dakota Nebraska border to Kimball, Nebraska.

The following results have been obtained. Data for hemispherical plots of bi-directional reflectance were obtained for solar zenith angles of 73.1 ± 0.6, 67.2 ± 0.2, 63.6 ± 0.3, 61.9 ± 0.1 and 63.7 ± 0.3 degrees. In addition a measurement of the bi-directional reflectance in the vertical direction was obtained for the entire interval of time 1050-1530 E. S. T.

The method of taking and analyzing the data was reviewed in the last progress report #05863-25-P, May 1969. A small portion of the data was also shown in that report. Figure 1 is a plot of bi-directional reflectance in the vertical direction as a function of time. The non-uniformities in the curve are explained on the figure. They are caused by clouds, cloud shadows, vegetation and a lake. A dependence on the solar zenith angle is also indicated, with the bi-directional reflectance varying from 5 at a zenith angle of 72.6^{o} to 7.2 at the minimum zenith angle of 62^{o}(noon) and then back to 5.8 at a zenith angle of 66.2^{o}.

The reflectance data obtained will be discussed completely in a technical report.

B. Filter Wedge Spectrometer Data

GSFC personnel have found that the data obtained by the Filter Wedge spectrometer on the 20 November balloon flight does not yield sensible results with normal data reduction procedures. Accordingly, some time has been spent here at the University in analyses of the data. A brief summary of this work since the balloon flight follows.

1. December, 1968 - Magnetic tape recordings and Brush Recorder records were prepared of the data obtained for the time interval from just before launch until just after float altitude was reached. These records were sent to GSFC.
2. January, 1969 - A second Brush recording of the same data was made with a different time scale and recorder gain more suitable for hand data processing. This record was sent to GSFC.

3. May 1969 - Filter Wedge calibration data was obtained from GSFC and flight recordings were analyzed here at Michigan. In-flight calibrations were used to determine corrections for a portion of the filter wedge data. This work is discussed in more detail below.

4. June, 1969 - Brush recordings of the Filter Wedge data for the 25 September 1968 environmental test and the entire balloon flight were prepared and sent to GSFC (later, in July these were redone with a time scale and gain more suitable for hand data processing.) Additional data including copies of quarterly progress reports, the ozoneogram taken at Boulder, Colorado on the day of the balloon flight and the Filter Wedge door time sequence of operations were also sent to GSFC.

The Filter Wedge data analysis carried out at Michigan consisted of the preparation of inflight calibrations and their application to a portion of the balloon flight data.

Inflight calibrations were obtained at six times before and during the flight when the Filter Wedge instrument compartment door was closed allowing the instrument to view a "blackbody" surface on the inside of the door (figure 2). The blackbody was made of 0.050 inch deep circular grooves cut into a 0.125 inch thick piece of magnesium. The surface was painted with 3M#101-C10 black paint. The temperature of the blackbody was determined by 2 thermister beads mounted on the back of the 0.125 inch thick magnesium plate.

The basic calibration data consists of values of door blackbody temperature T_D, the instrument reference blackbody temperature T_R and a Brush recording of the instrument output voltage. At each wavelength of interest the value of the blackbody radiant emittance

$$W(\lambda_I, T) = \frac{1.1905\cdot\quad\cdot 10^4}{\lambda^5\left[\exp\frac{1.4385\cdot 10^4}{\lambda T} - 1\right]} \qquad \left(\frac{\text{watts}}{\text{cm}^2\cdot\text{micron}}\right)$$

for each wavelength of interest, was calculated. Values of the quantity

$$W = W_D - W_R$$

were then plotted as a function of the instrument voltage output V. W_D and W_R are values of the blackbody radiant emittance corresponding to the temperatures T_D and T_R respectively.

Most of the data used was limited in accuracy because analog Brush recordings were used. More precise results could be obtained by digitizing the telemetered signals.

Although the range of inflight calibration data obtained was limited, comparison with preflight calibration data made at GSFC indicated that the difficulty with interpretation of the data might be due to a voltage offset not accounted for inthe data recording and analysis. The value of this apparent offset voltage for each of the wavelengths 8.0, 8.5, 9.0, 9.5, ..., 15.0, 15.5 μm were obtained as a function of time during the flight. Curves of the offset for three wavelengths (9.5, 11.0 and 15.0μm) are shown for reference in figures 3-5.

Data for three wavelengths (9.5, 11.0 and 15.0μm) was then reduced for the time interval 0817 to 1048 EST. During this time the balloon was ascending to float altitude. The results are shown in figure 6. Equivalent blackbody temperatures are given as a function of time. Data obtained with the U. of M. interferometer spectrometer are also shown for comparison at 1004 and 1047 EST. Although agreement between interferometer and Filter Wedge are mainly good for 9.5 and 11.0μm, there seems to be considerable disagreement for the 15μm data.

Some of the disagreement may be due to clouds in the field of view, however the ruling factor is without a doubt, the lack of precision in the analog Brush recordings and hand data analysis. An additional complication is the fact that the interferometer data has 3 cm^{-1} resolution where as the Filter data have about 20 cm^{-1} resolution at 11 microns (see figure 7).

It can be seen that compairson of the 20 cm^{-1} Filter Wedge data with the interferometer results would require careful consideration of instrument line shapes and resolution for both the 9.5μm and 15.0 μm readings.

It is concluded that valid offset voltage corrections to the Filter Wedge calibration data can be calculated in this fashion and that the complete set of data should be analyzed using analog to digital conversions of the telemetry data and computer calculations.

C. U. of M. Interferometer Data

1. Instrument Calibration and Data Processing Problems

Several problems have been encountered in the data analysis. Some of the problems are associated with the fact that the instrument was operated in a one-sided mode in order to double the resolution. Other problems are associated with equipment failures during the balloon flight.

Operating in the one sided mode has greatly increased the computing time for each spectrum and results in a filtering of the spectrum which causes radiances on the edges of large absorption bands to be incorrect. This filtering effect must be corrected for.

Failures of electronic components in the calibration blackbody circuits resulted in a loss of accuracy of the inflight calibrations by approximately a factor of two.

2. Inversion of 15μm CO_2 Band Data to Atmospheric Temperature Structure. (by S. R. Drayson).

To obtain temperature profiles from satellite or high altitude balloon measurements of thermal radiation, highly accurate radiance measurements are required. Random noise will result in temperature oscillations in the solution profile, while systematic errors, such as can arise from uncertain calibration of the instrument, will produce a solution which resembles the true profile, but which is displaced toward higher or lower temperatures.

The experimentally determined radiances from the November 1968 balloon flight are shown in the upper curve of Fig. 8. The lower curve is the theoretically calculated radiance using a radiosonde sounding from a nearby location on the same date (see Fig. 9). The theoretical curve is considerably lower at all wavenumbers.

It is appropriate to consider the accuracy of the theoretical calculations. The method of computation is the same as that reported on an earlier balloon flight of a similar instrument (Chaney, Drayson and Young, Applied Optics 6, 367, Feb. 1967), where highly satisfactory agreement between theoretical and experimental data was obtained. Absorption by water vapor has not been included, but this would tend to increase the divergence between the two curves away from the band center and have no effect near 15μm. Similarly the slight modification provided by the 14μm ozone band has been neglected. It must therefore be concluded that although the shape of the experimental curve agrees quite well with the theoretical (especially when allowance is made for the higher resolution of the measured curve) the absolute values of the experimental radiances are not reliable.

It would be anticipated that any inversion attempted with such measurements would produce a temperature profile that is rather warmer than the actual profile. Fig. 9 shows that the inversion solution is everywhere warmer than the radiosonde profile by about 5 to 8 K. The exception to this result is near the surface, where the atmosphere is opaque at the wavenumbers used to obtain the solution and the climatological mean or 'first guess' profile is virtually unmodified.

A satisfactory solution could almost certainly be obtained by adjusting the calibrations so that the experimental curve agreed closely with the theoretical values. Fig. 19 shows the resulting temperature profile solution after an attempt to revise the calibration of the instrument, bringing the experimental radiances much nearer to the theoretical values. The temperature profile is now much closer to the radiosonde sounding. However, this procedure to a large extent negates the purpose of measurement program, to test the instrument and demonstrate the feasability of obtaining temperature soundings from remote observations.

III. Measurements of the 15μm Absorption Band of CO_2

A. Medium Resolution Measurements

The results of the work on medium resolution measurements of the 15μm band of CO_2 which is described in the Doctoral thesis of Henry Reichle, Jr., (report #05863-17-T) is being applied to improve 15μm CO_2 band transmissivities for temperature inversion purposes.

B. High Resolution Measurements (by L. W. Chaney)

It is planned that the high resolution measurements of CO_2 (better than 0.05 cm^{-1}) be carried out with the 1.8 meter Jarrell-Ash instrument located at Willow Run.

The instrument was last used for lower resolution studies and was equipped with a thermocouple detector. In order to make the measurements that we desire, a more sensitive detector is required. Furthermore, the instrument must be modified for vacuum operation.

The group at Willow Run has several copper doped germanium detectors which were originally used with scanning radiometers. Examination of the detectors and the spectrometers indicated that it would be possible to adapt at least one of the CU:GE detectors to the Jarrell-Ash instrument.

Two designs were proposed and drawn up. The first design used infra-red lenses originally purchased for the interferometer project. The second design used an ellipsoidal mirror. The advantage of the first design was its low cost. The lenses were available and only a small amount of shop work was required.

However, in reviewing the design, it was found that the detector had a mask one millimeter in width by 4 mm high. The mask could not be altered and the circle of confusion of the lenses was about 1 mm. The conclusion was that a significant portion of the total energy would be lost.

The second design was selected. The elliptical mirror was purchased and the mechanical modification was designed and constructed. The basic modifications are shown schematically in figure 11.

The new housing will be vacuum tight with fittings designed so that the slits can be adjusted through the chamber walls.

Detailed drawings of the vacuum feed through slit adjustment, the CU: GE detector adaptor and the detector mounting apparatus are shown in figures 12, 13 and 14, respectively.

IV. Determination of Atmospheric Ozone Amounts Using Radiance Measurements in the 9.6μm Band

(by J. M. Russell)

In order to determine the information content of radiance measurements taken in the 9.6μm ozone band an eigenvector analysis of the least squares matrix representation of the problem was performed. The analysis showed that there is at most only two independent pieces of information available in radiance data taken as a frequency scan in either the 0° or 75° zenith directions. Since it is difficult to determine a detailed atmospheric ozone profile with so little independent information the study was oriented toward determination of only the integrated ozone amount in an atmospheric column of unit cross-section. An extensive error analysis was performed which considered effects due to random radiance error, radiance bias error, atmospheric temperature profile bias error, atmospheric temperature profile plus and minus errors (such as might be obtained by existing temperature inversion techniques), lower boundary temperature errors, and errors in ozone absorption line intensity. It can be generally concluded that the error in ozone column density is affected most by errors in the lower boundary temperature and random radiance errors and is least affected by all errors when the zenith angle is 75° rather than 0°.

Currently, the inversion method which was developed is being applied to recent Nimbus satellite radiance data in an attempt to infer ozone column density.

V. Laboratory Tests of the IRIS Interferometer

The technician who had been ill for six weeks as a result of a heart attack, returned to work and completed the calibration of the IRIS-B interferometer. The data have been sent to the General Electric Co. for processing.

VI Microwave Occultation Studies

(by F. F. Fischbach)

The method of inverting microwave occultation data by using empirical orthogonal functions rather than Abelian transform has been adopted by the Stanford University proposer. We are in substantial agreement that the Abel transform method cannot be useful when less than one daughter satellite per 5 km of atmosphere (vertical) sounded is employed. The current proposal is for four daughter satellites and sounding between perhaps 5 and 35 km tangent height, therefore the empirical orthogonal function approach would appear to be required.

Stanford has developed the empirical orthogonal functions for one site and has reduced simulated data of limited amount. They report success with the method, but this is not yet published in any form and we have not had the opportunity to examine the data or method. The obvious drawbacks to this approach is the difficulty of determining effectiveness statistically from very limited sampling.

The empirical orthogonal function approach also allows the possibility of eliminating the errors due to water vapor. To prove that this will or will not be effective would appear to require a very large number of samples. Accordingly, further analysis of the Abel transform method was suspended in the interest of economy and the remainder of the effort will be used to plan a program of statistical sampling, in conjunction with Stanford, which will best demonstrate the effectiveness of the method within a reasonable computer budget.

VII. Study of Measurement Techniques and Existing Data on Molecular Collision Rates

This study was completed with a proposal to implement laboratory measurements entitled "Measurement of Collisional Relaxation Times for

Infrared Active Atmospheric Gases."

The proposal stresses the major importance of a more accurate knowledge of relaxation times in order that a better understanding of the physics of the upper atmosphere may be achieved. An improved technique for the measurement of relaxation times in the temperature range of 200°K to 300°K is proposed.

VIII Reports Published

Quarterly progress report 05863-25-P, covering the period 1 January 1969 to 31 March 1969 was published and distributed in May 1969.

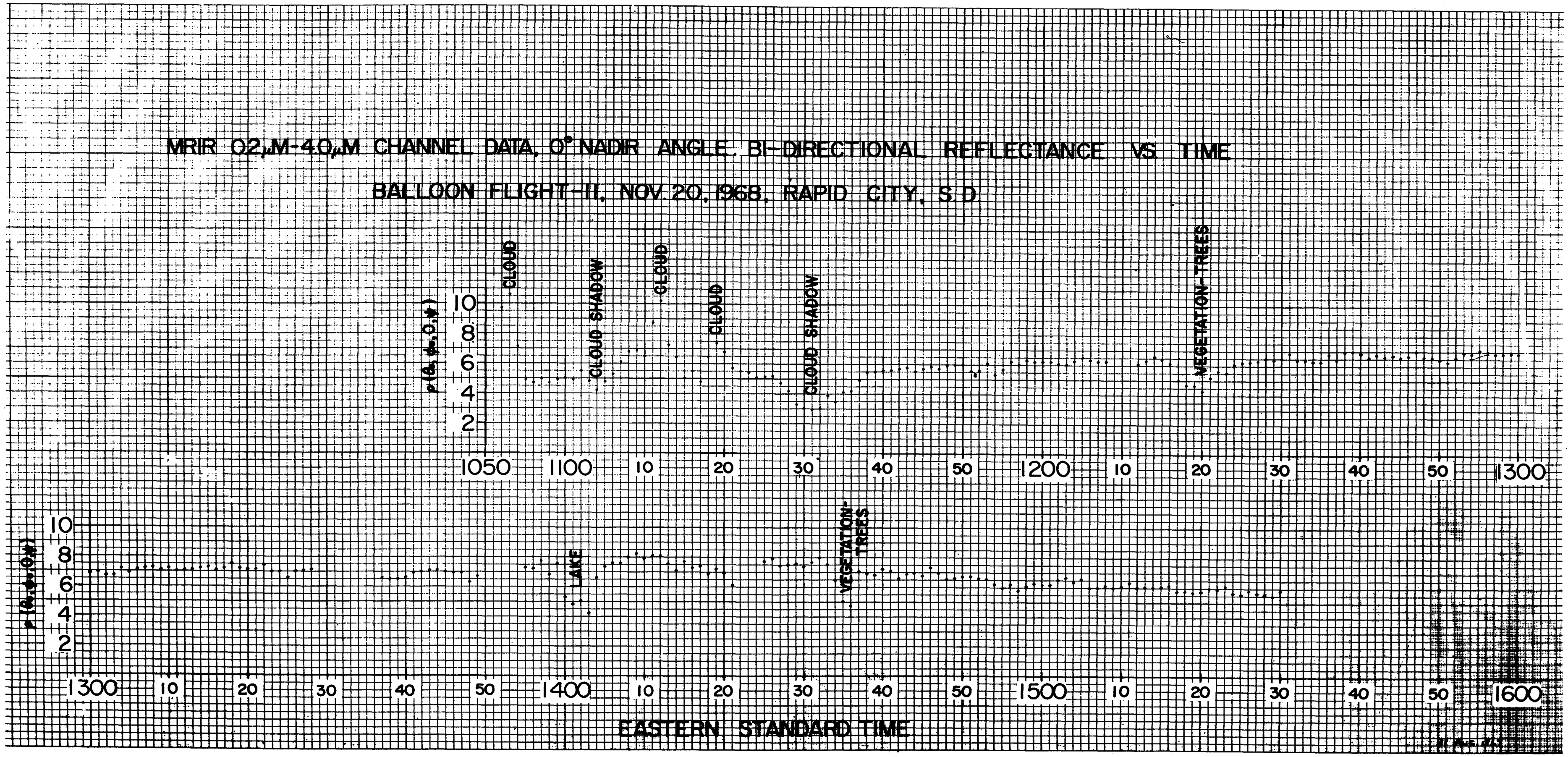


Figure 1 Vertical bi-directional reflectance as a function of time-barren surface in northwest Nebraska - 20 November 1968 balloon flight

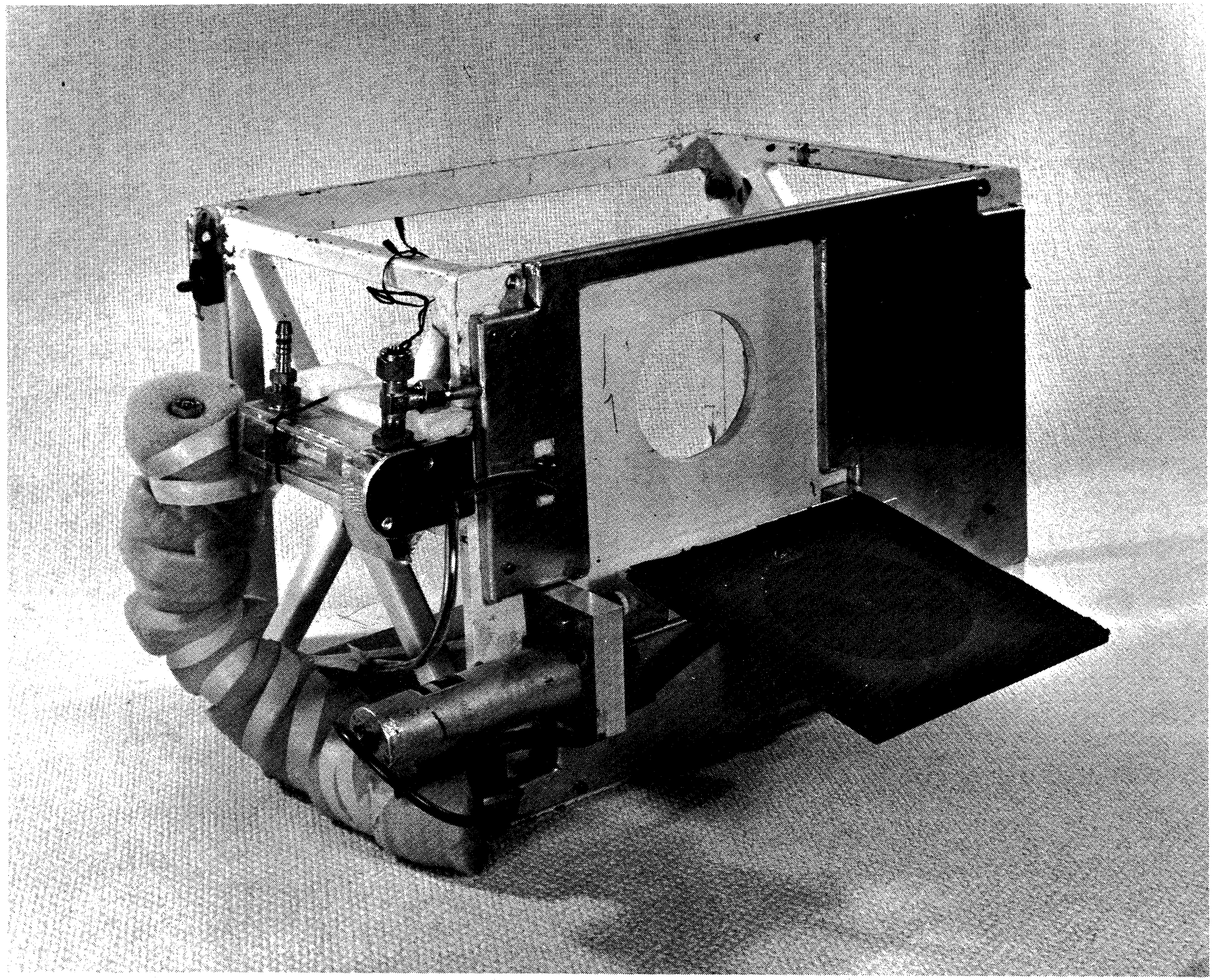


Figure 2 Filter Wedge compartment door with blackbody

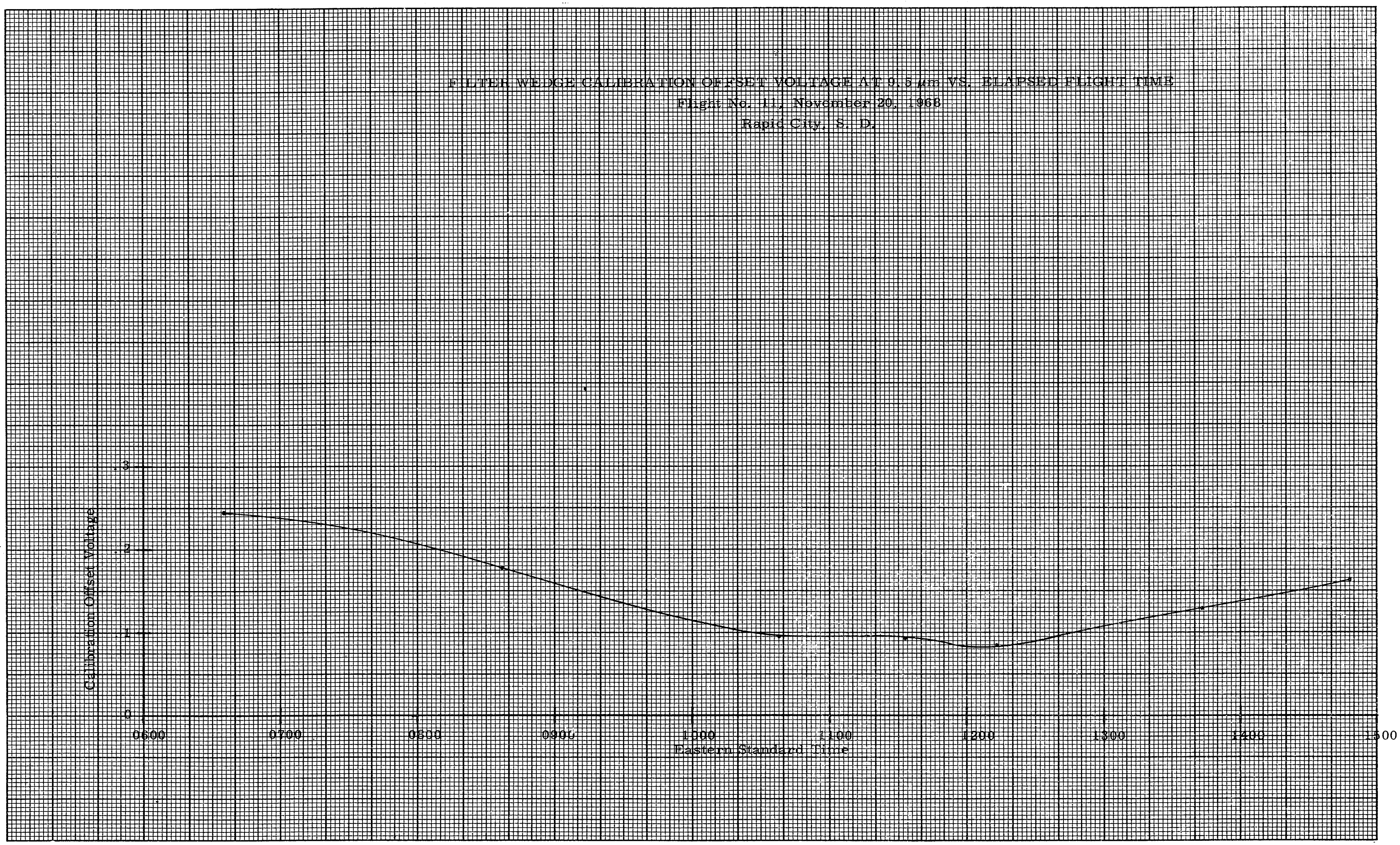


Figure 3 9.5μm calibration offset voltage vs. time, 20 November 1968 balloon flight.

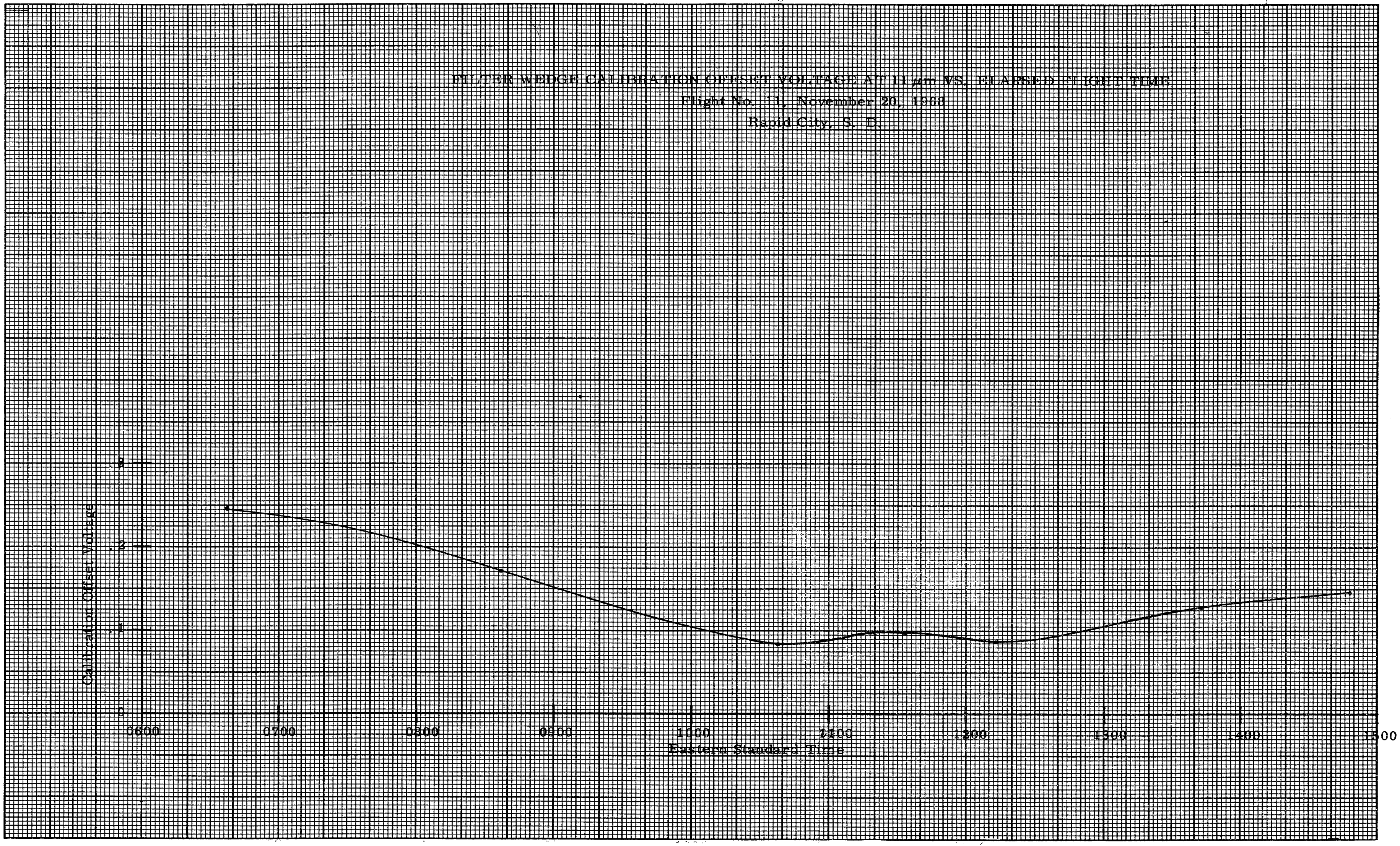


Figure 4 11.0μm calibration offset voltage vs. time, 20 November 1968 balloon flight

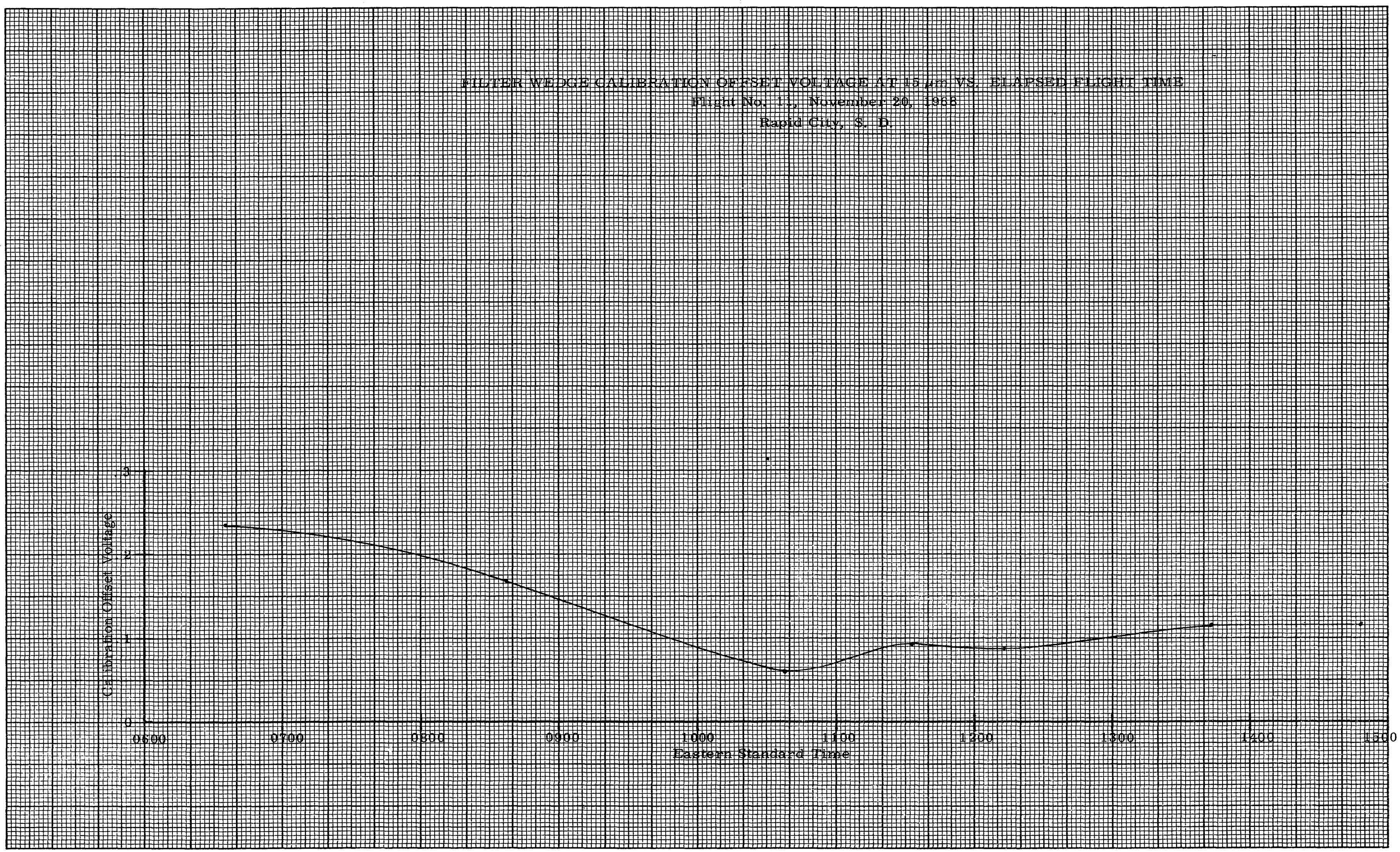


Figure 5 15.0μm calibration offset voltage vs. time, 20 November 1968 balloon flight

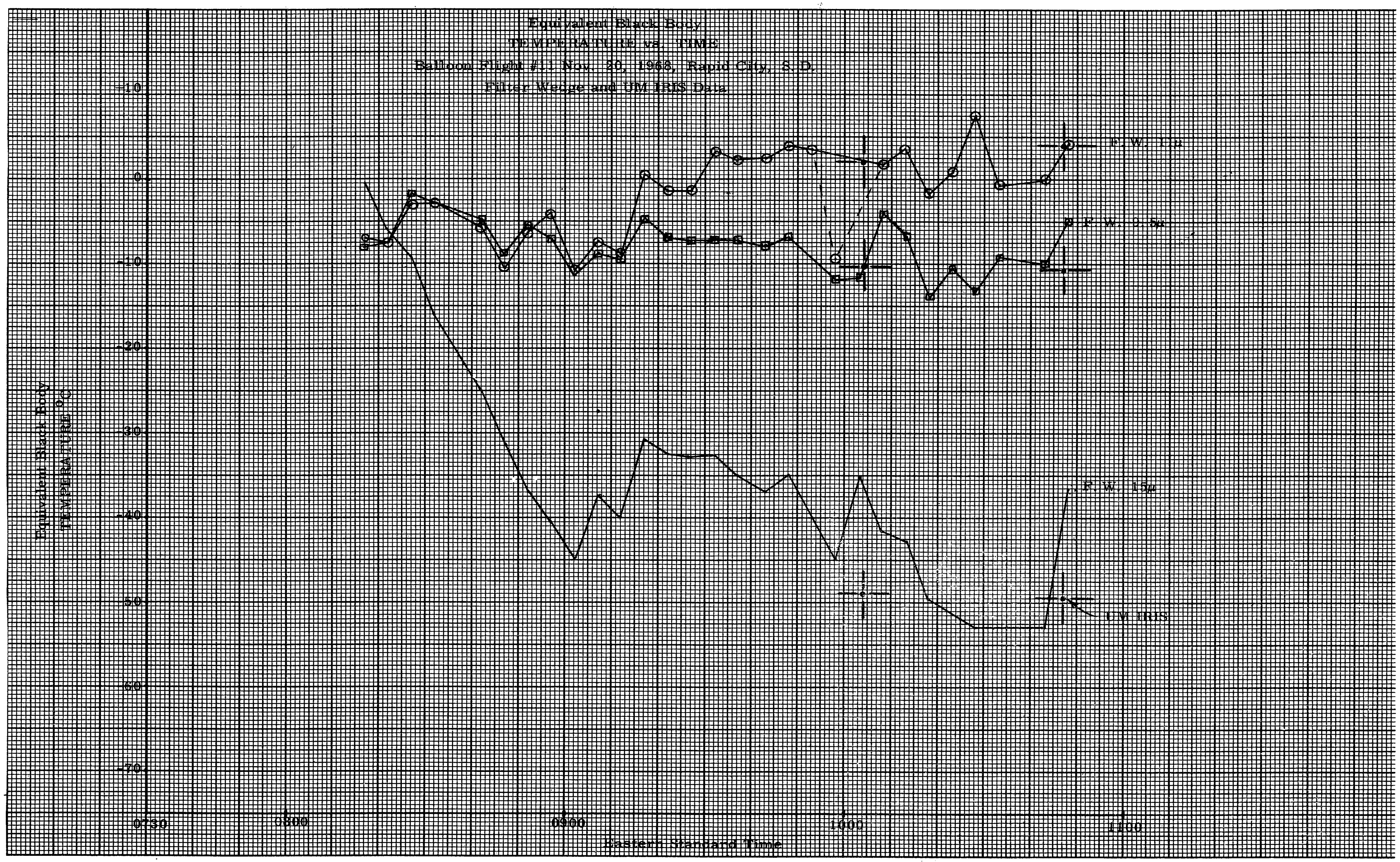


Figure 6 Equivalent blackbody temperature vs. time at 9.5, 11.0 and 12.0μm Filter Wedge spectrometer on 20 November 1968 balloon flight

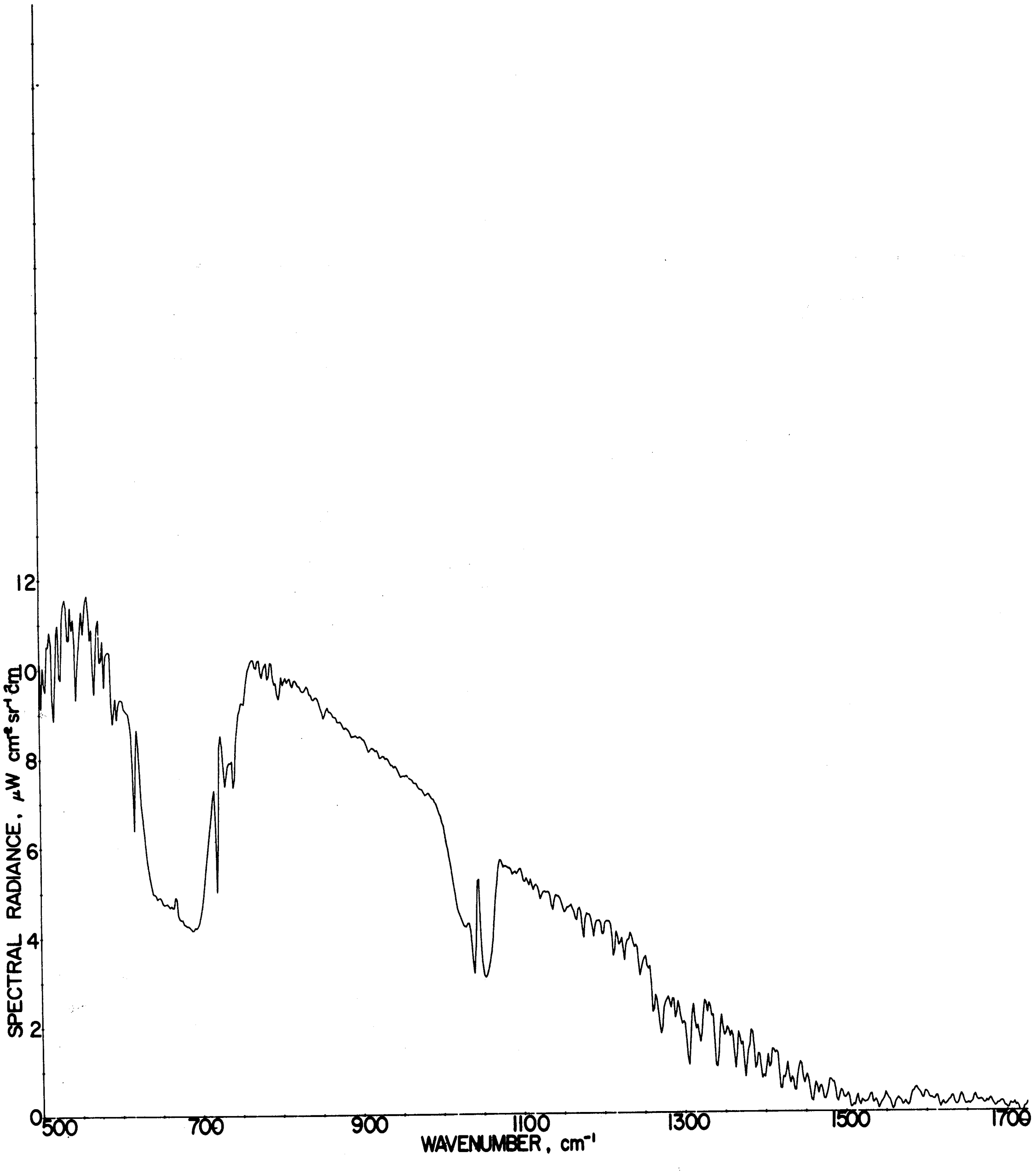


Figure 7 Interferometer radiance data, 20 November 1968 balloon flight

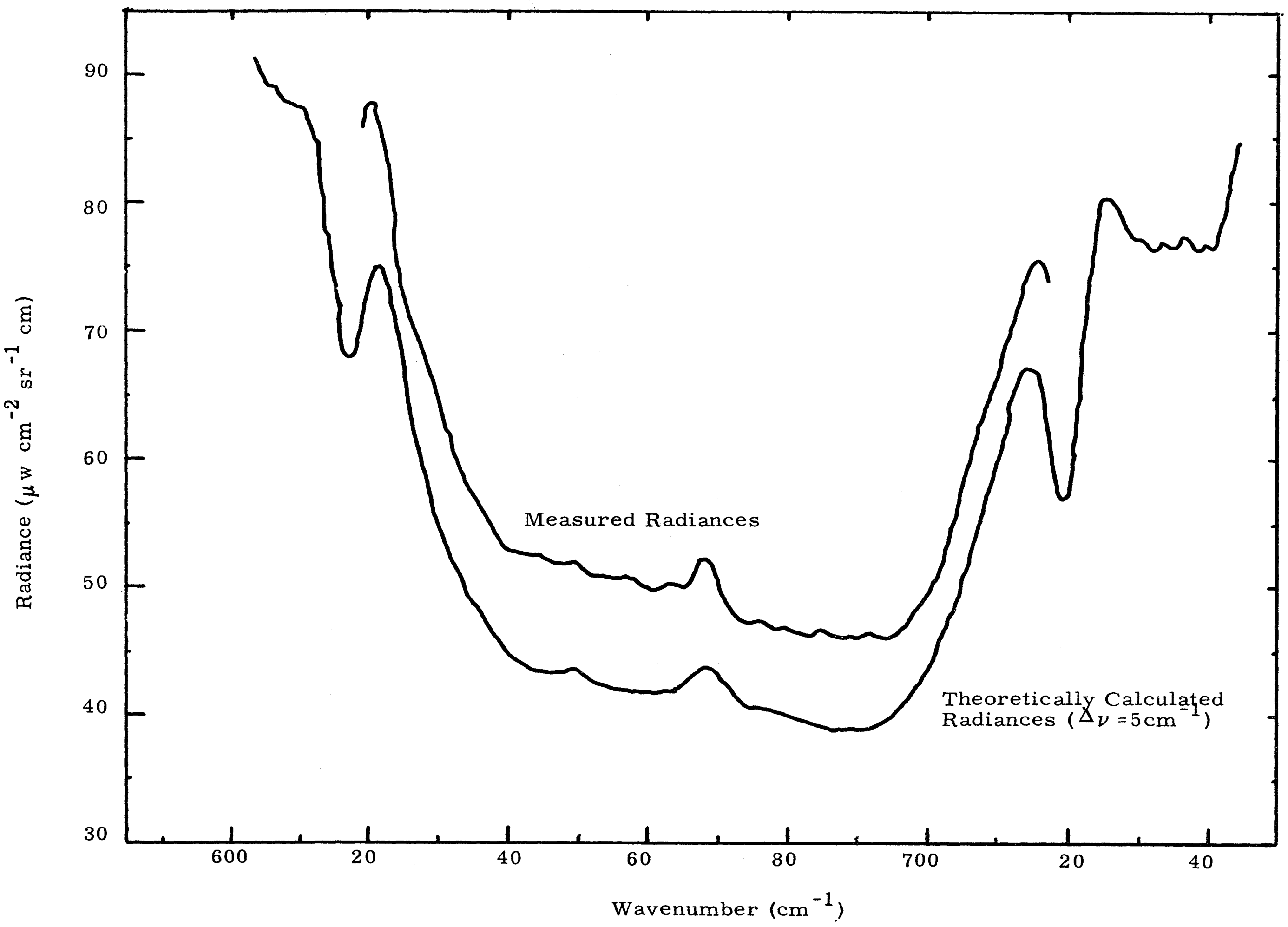


Figure 8 Comparison of computer and measured spectra
20 November 1968 balloon flight

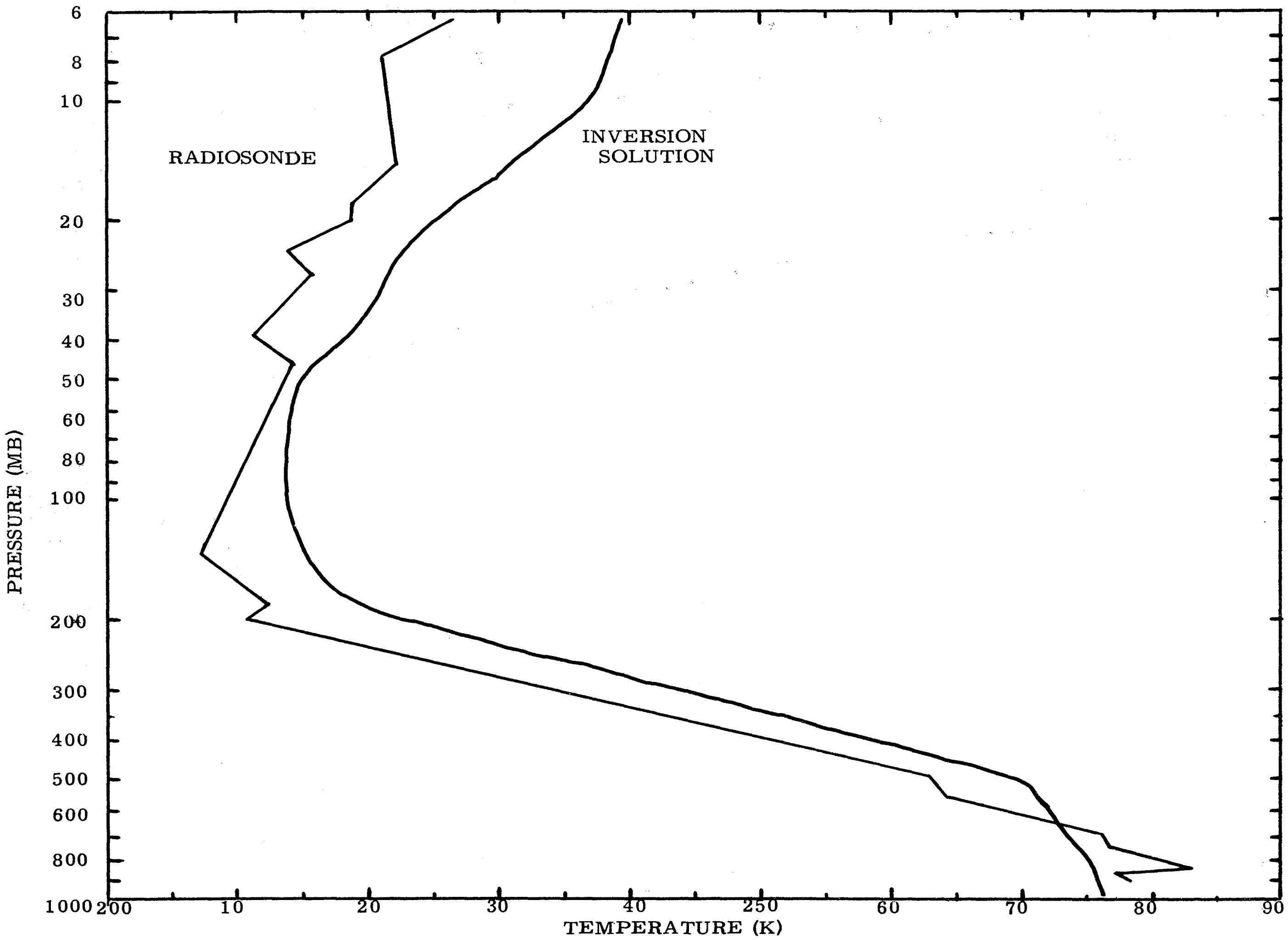


Figure 9 Comparison of radiosonde and inversion temperature profiles, 20 November 1968 balloon flight

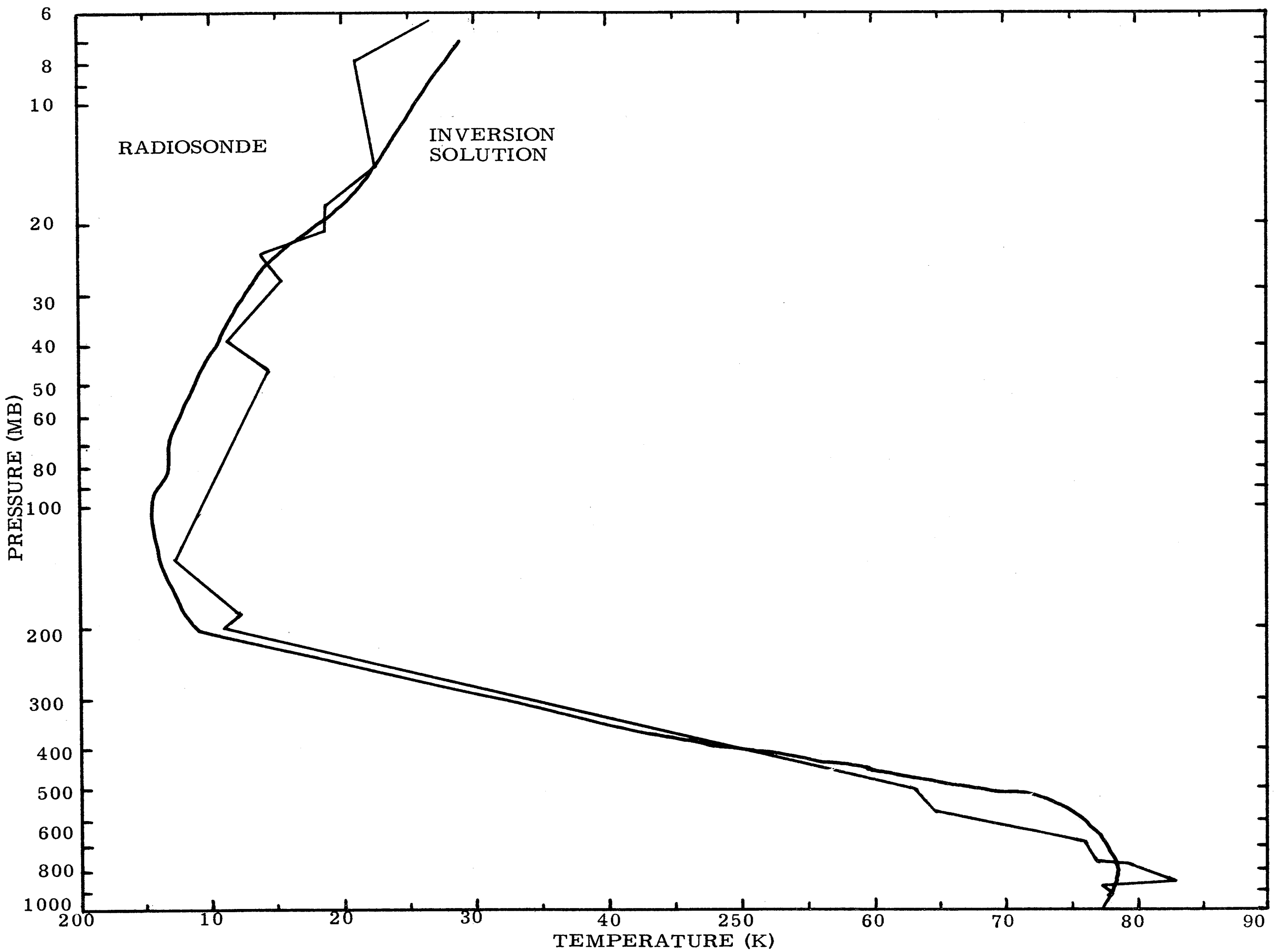
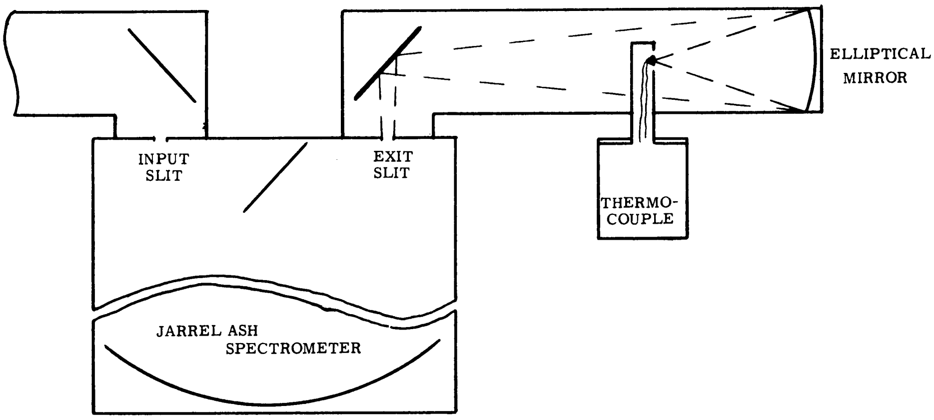


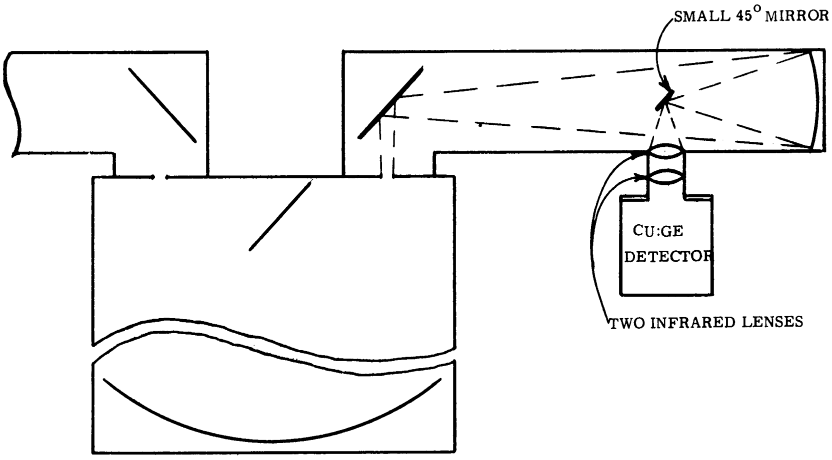
Figure 10 Compairson of radiosonde and revised inversion temperature profiles, 20 November 1968 balloon flight

BASIC INSTRUMENT PRIOR TO MODIFICATION



MODIFICATION CONSIDERED INITIALLY

1. Add small 45^{o} mirror at focus
2. Mount doublet and detector in original housing.



MODIFICATION SELECTED

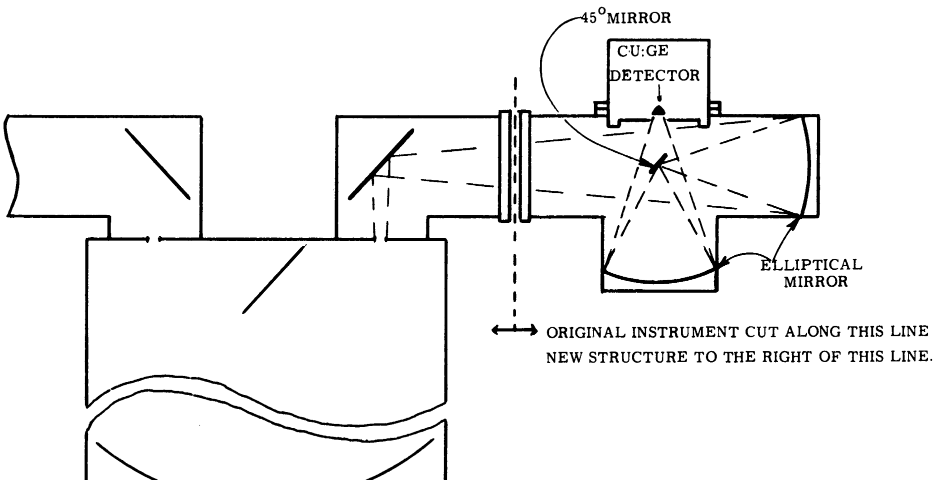


Figure 11 Schematic diagram of methods of adapting Jarrell-Ash 1.8 spectrometer for use with CU:GE detector.

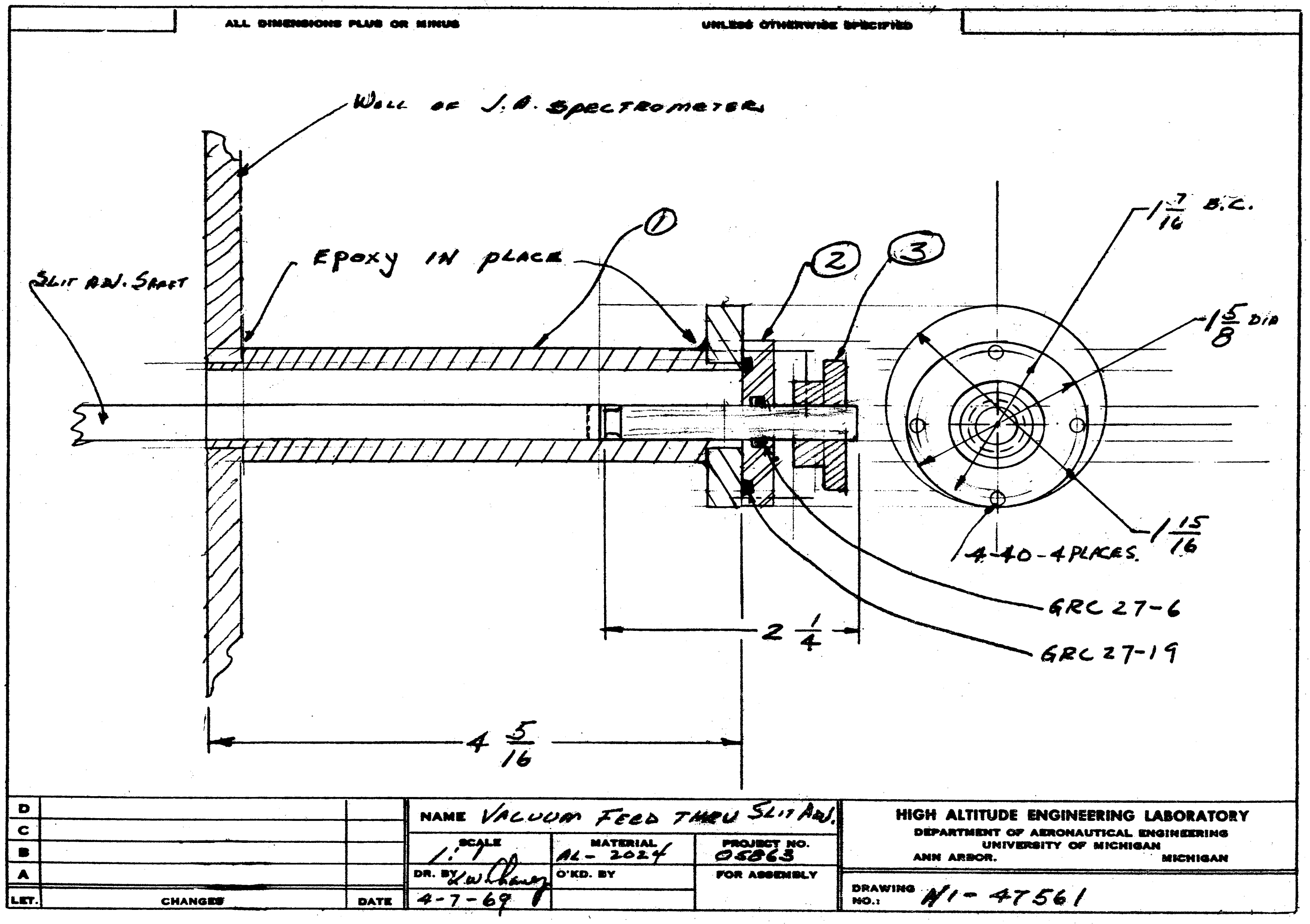


Figure 12 Vacuum feed thru slit adjustor

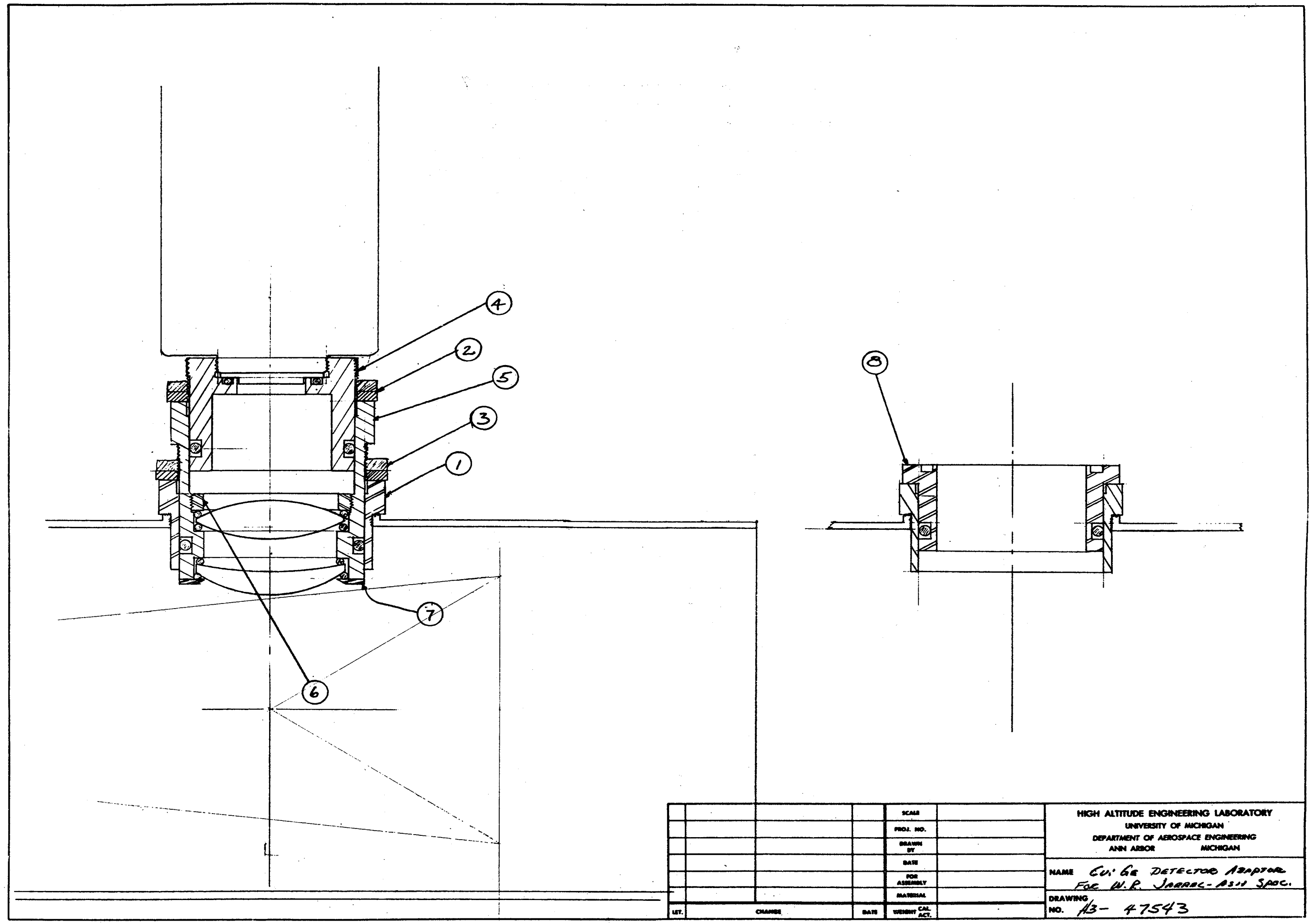


Figure 13 CU:GE detector adaptor for W. R. Jarrell-Ash Spectrometer

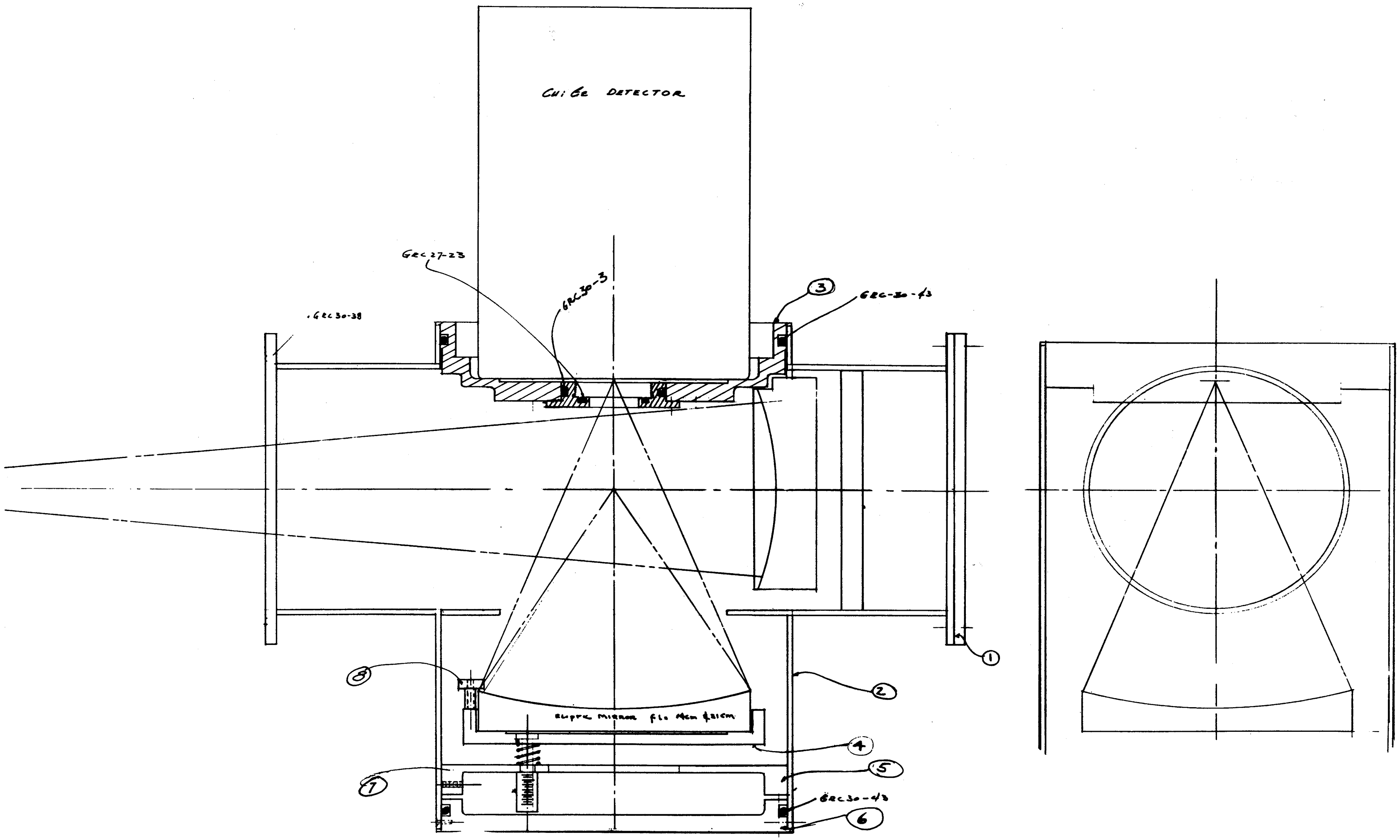


Figure 14 CU:GE detector mount for W. R. Jarrell-Ash Spectrometer-elliptic mirror