NASA TECHNICAL NOTE

NASA TN D-3491

c. 1

LOAN COPY: RETURN
AFWL (WLIL-2)
KIRTLAND AFB, N M

TECH LIBRARY KAFB, NM
0130387

NASA TN D-3491

TEMPERATURE CONTROL UNIT FOR SOUNDING ROCKET APPLICATIONS

by Kerstin Fredga and Robert S. Lee

Goddard Space Flight Center
Greenbelt, Md.

24 OCT 1966

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • OCTOBER 1966

TECH LIBRARY KAFB, NM

0130387

TEMPERATURE CONTROL UNIT

FOR SOUNDING ROCKET APPLICATIONS

By Kerstin Fredga and Robert S. Lee

Goddard Space Flight Center
Greenbelt, Md.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151 – Price $1.00

ABSTRACT

Sounding rocket experiments sometimes utilize instruments requiring very close temperature control. A device was designed to fulfill this type of temperature control requirement for an optical birefringent filter and did so successfully on board three Aerobee 150 sounding rockets. It utilizes solid-state circuitry with Peltier thermoelectric heat pumps for temperature control. The mechanical and electronic design of this device are discussed in detail as well as the laboratory and in-flight performance data.

CONTENTS

TEMPERATURE CONTROL UNIT FOR SOUNDING ROCKET APPLICATIONS

by
Kerstin Fredga* and Robert S. Lee
Goddard Space Flight Center

INTRODUCTION

This paper describes the mechanical and electronic design of a precision temperature control unit utilizing solid state circuitry with Peltier thermoelectric heat pumps for temperature control. The unit was used to control the temperature of a temperature-sensitive optical birefringent filter. It was successfully used on board three Aerobee 150 sounding rockets (NASA numbers 4.49, 4.53 and 4.145) that were launched in April, October, and December respectively of 1965 from White Sands Missile Range, New Mexico. The controlled temperature was maintained at 11.0 °C on the first flight, and at 13.7 °C on the two later flights.

MECHANICAL DESCRIPTION

An exploded view of the mechanical construction of the temperature control unit is shown in Figure 1.

The optical filter is a Solc type birefringent filter with a spectral passband of 3.5A centered at 2802.7A. The transmission peak of the filter shifts -0.17A per degree C rise in temperature. The temperature-sensitive elements consist of a number of uniformly thick retardation plates of birefringent quartz mounted inside an aluminum tube. In

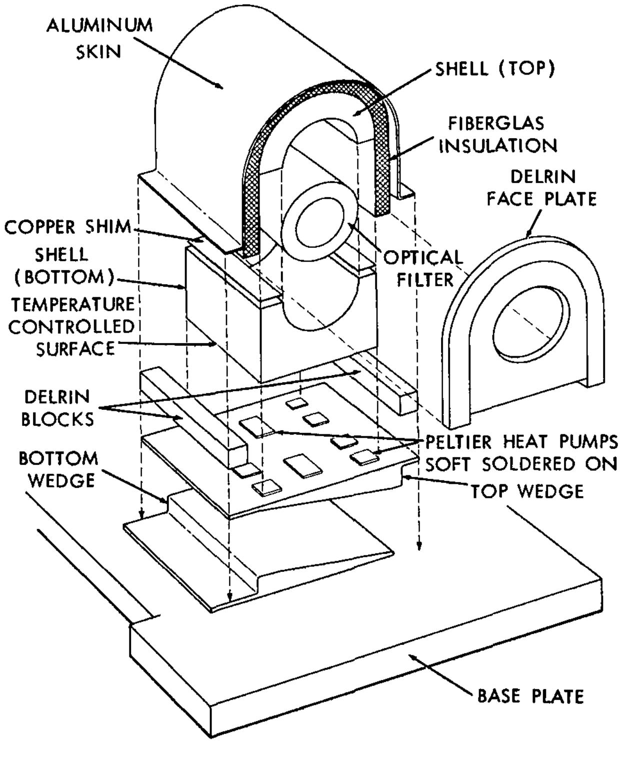

Figure 1—Exploded view of mechanical construction.

*NASA–National Academy of Sciences, National Research Council Postdoctoral Research Associate on leave of absence from the Royal Institute of Technology; Stockholm, Sweden.

the experiment it was found desirable to control the temperature of the optical filter to within ±1°C.

The filter as a whole was surrounded by a thermal mass consisting of the top and bottom shell. Copper shims of proper thickness were placed between the two halves of the shell to ensure best possible thermal contact between the optical filter and the inside surface of the shell.

The Peltier heat pumps were soft-soldered on to the top wedge, and the temperature-controlled surface (bottom surface of the shell) was pressed against the top of the heat pumps for efficient heat transfer. The top and bottom wedges were mounted on the experiment base plate. This 14-pound aluminum base plate was the main heat reservoir for the Peltier heat pumps. The angled surfaces of the top and bottom wedges facilitated optical alignment and at the same time maintained good thermal contact.

A temperature probe (thermistor) was mounted in the middle of the temperature-controlled surface to measure the temperature of this surface. The analog output of this temperature probe served to control the electronic circuit.

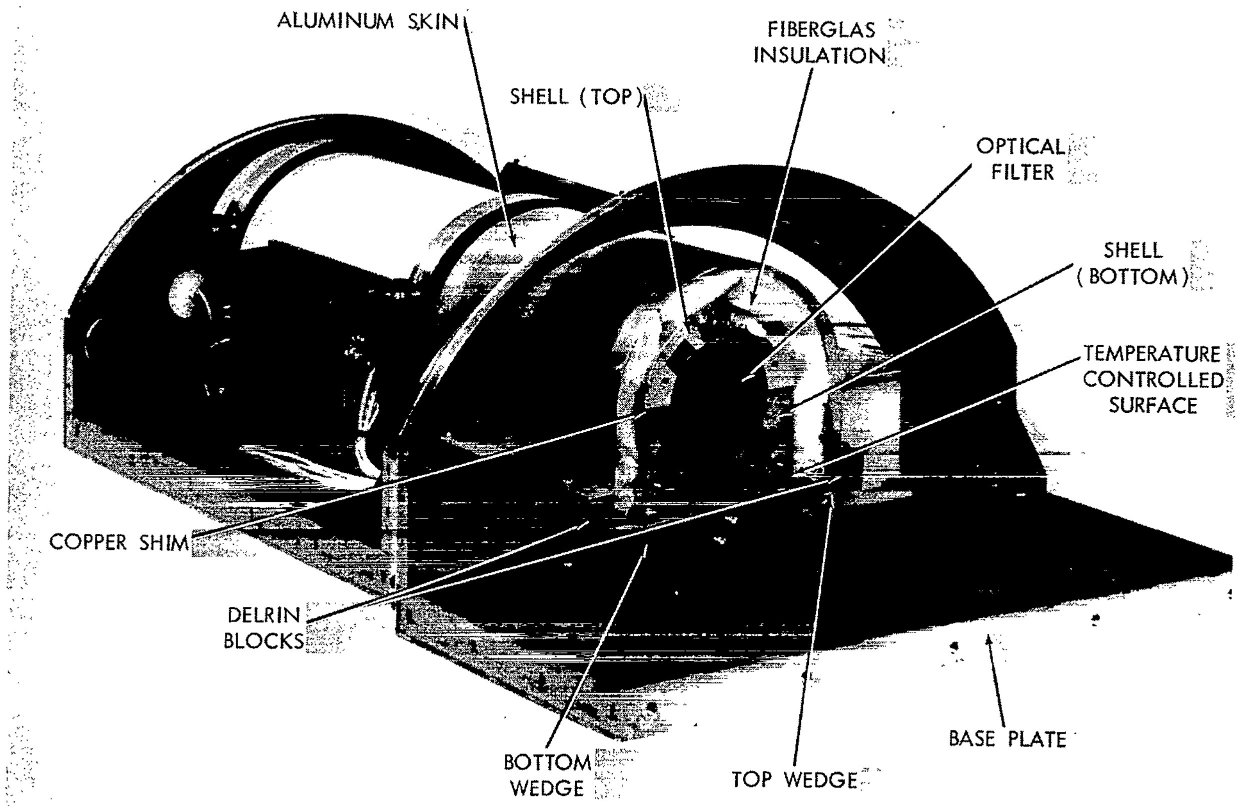

Figure 2—Assembled flight unit with one end exposed.

A 1/2 inch fiberglass insulation ensured minimum heat transfer between the two halves of the shell and the ambient environment. An aluminum "skin" and two Delrin face plates completely enclosed the insulation and the shell, with openings only on the face plates along the optical axis.

Two Delrin blocks were employed to insulate the aluminum skin from the top surface of the top wedge. All surfaces which required good thermal contacts were lapped to ensure flatness and smooth fit. With exceptions as noted in Figure 1, all parts were machined from aluminum blocks.

The mechanical structure of the flight unit was rugged enough to pass the Aerobee 150 vibration specifications: 10 G, 5-2000 cps, sine and random, on all three axes. Indeed, one unit was used twice, and survived both flights.

The photograph (Figure 2) shows the flight unit assembled on the flight experiment base plate, with one end exposed.

ELECTRICAL DESCRIPTION

The temperature-controlling elements were ceramic type Peltier heat pumps (Materials Electronic Products Corp. Type CP2-31-10), made of bismuth-telluride base quarternary alloys.

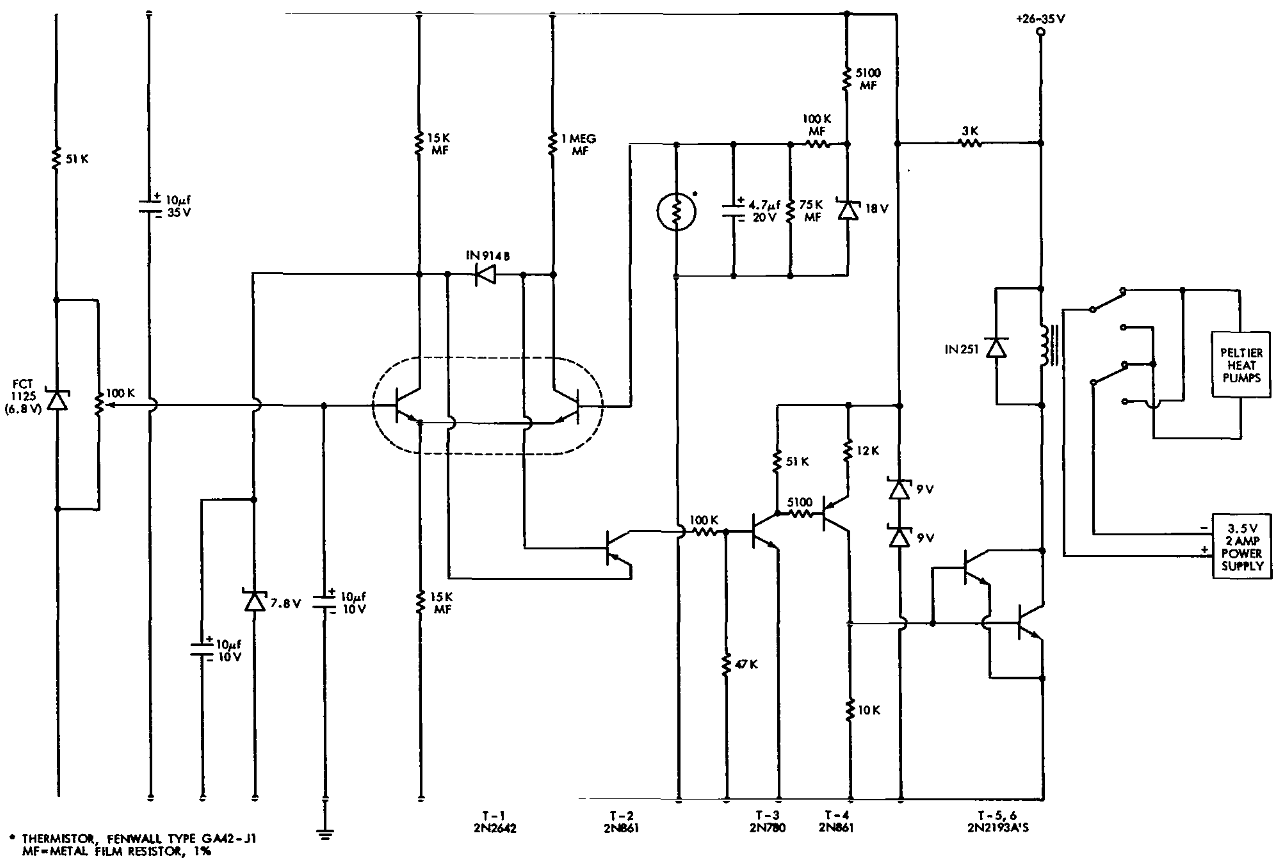

Figure 3—Schematic diagram.

Heat could be transferred from either surface of the heat pumps to the other by controlling the direction of current flow. Consequently, the system may be used for both heating and cooling.

As is shown in Figure 3, the sensitive differential amplifier, T-1, consists of a matched pair of 2N930 transistors in a TO-5 case (Texas Instrument Type 2N2642). The amplifier will react to a small voltage change (1.5 mv) due to resistance change of a thermistor. The output of the amplifier goes through three succeeding stages of amplification, T-2, T-3 and T-4. Transistor T-4 is used to turn on a parallel pair of 2N2193A's, which in turn activates a double-pole-double-throw relay, controlling the direction of current flow through the Peltier heat pumps.

There is sufficient gain in the system that a 1.5 mv change at the differential amplifier input will cause the relay to react. The resistance of the selected thermistor dictates relatively high input impedance at the differential amplifier. A combination of high gain and high input impedance makes the circuit sensitive to noise, both radiated and induced. The shielding of both the electronic circuits and input lines would reduce the effect of radiated noise, while an isolated power supply would appreciably reduce the susceptibility of the circuits to line noise. However, these precautions were not taken in the flight unit owing to time limitations.

The thermistor voltage changes about 0.1 V/°C (Figure 4); thus 1.5 mv represents a relative temperature change of 0.015°C. Theoretically then, ±0.0075°C is the limit within which one can control the temperature-controlled surface, but this is not possible because of thermal overshoot resulting from the thermal mass of the heat pumps.

The temperature probes used are Fenwal Electronics Type GS42-J1 sensors embedded in Fenwal Type H-34 probes. During calibration, a block of aluminum 26.5 inches square by 12 inches high served as a thermal mass, with two mercury thermometers graduated to 0.1°C as references. The output voltage of the Fenwal probes (approximately 2.8 V at +13°C) was measured with a 5-place digital voltmeter. The calibration curve for each temperature probe was plotted on linear paper at intervals of 0.01 V and 0.1°C.

The Peltier heat pumps used required +3.5 V at 2 amps. However, they are now available with higher voltage ratings and lower current requirements.

THERMODYNAMICAL CONSIDERATIONS

In order to simplify the mechanical design procedures and requirements, some basic assumptions were made concerning thermodynamical considerations. Although departures from these assumptions may actually have occurred, they were considered to have negligible effects on the performance of the finished unit. The following assumptions were made:

(1) The fiberglass insulation around the shell is sufficient to prevent appreciable heat transfer between the shell and the environment outside the aluminum skin. Consequently, changes in the environmental temperature have only a small effect on the controlled temperature.

(2) The thermal conduction efficiency is good for all contacting surfaces that are required to conduct heat.

(3) The top surfaces of the Peltier heat pumps make good thermal contacts with the temperature-controlled surface, resulting in an even temperature distribution throughout this surface.

(4) As a result of 1, 2 and 3, the temperature gradient between the upper and lower portions of the filter, as well as along the filter, is negligible.

(5) The system is not affected by vacuum if all conducting surfaces are lapped and carefully cleaned.

(6) Temperature change due to thermal overshoot at the temperature-controlled surface (because of the thermal mass of the heat pumps) is reduced to a minimum by the shell (thermal damping) surrounding the optical filter.

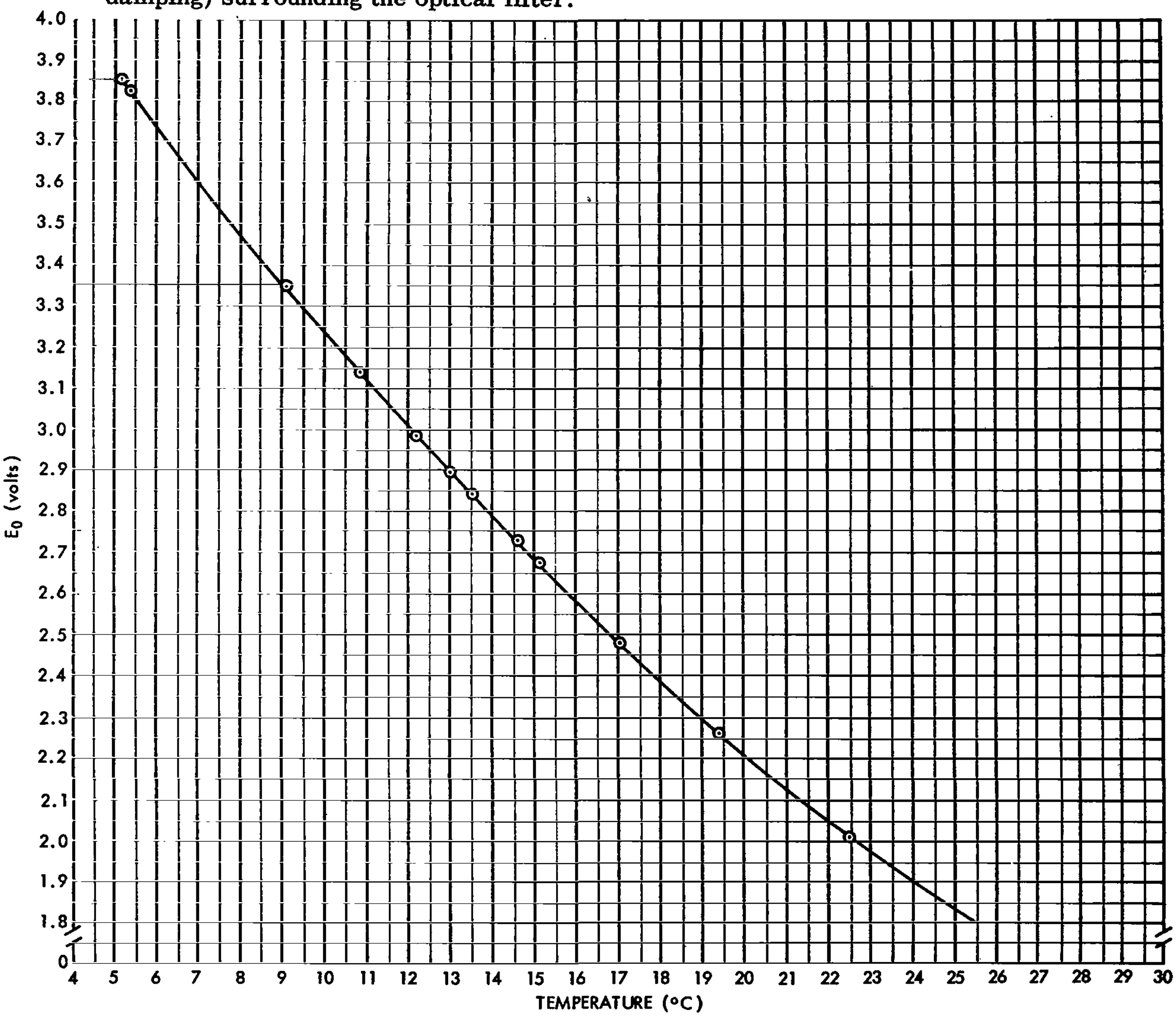

Figure 4—Temperature calibration curve for filter front thermistor.

RESULTS

Because tests can be performed with much better accuracy in the laboratory than in flight, the results are presented in two sections: Laboratory Data and Flight Data.

Laboratory Data

Laboratory tests were made with the mechanical portion of the temperature-control unit assembled in flight configuration. For test purposes, a dummy optical filter of aluminum was made to the exact dimensions and mass of the flight filter. Temperature sensors were mounted on both lower front and upper rear portions of the filter to measure temperature gradient. A 5-place digital voltmeter was used to measure the output voltages of the temperature sensors, so that a 0.001°C change in temperature could be read.

Some laboratory test data in simplified form are presented in the table below. All temperature figures given are mean values. Maximum variations from the set temperature were measured to be ±0.015°C at the optical filter. It must be remembered that voltages are measured to 0.1 millivolt, where line noise, R. F., and 60 cycle radiations contribute to the error. During laboratory tests under ideal conditions (room lights off, heavy machinery and building air-conditioning off) the indicated deviation from the set temperature was only ±0.0075°C.

As is shown in Table 1, when the optical filter temperature was below the ambient temperature, the lower portion of the filter was slightly cooler than the upper portion, while the reverse was true when the filter temperature was above the ambient. The data show that the filter's temperature was only slightly affected by the longer conduction path to its upper portion, and that there was some heat flux transfer between the shell and the ambient environment.

Table 1

Laboratory Data Taken at Room Temperature (24°C).

Location	Temperature (°C)					
Optics Front (Lower)	9.95	11.95	16.50	29.30	37.85	47.05
Optics Back (Upper)	9.95	12.00	16.55	29.20	37.80	47.00

A vacuum test of the flight unit was performed by placing the mechanical portion in a vacuum tank, letting the dummy optics stabilize to the desired temperature, then pumping the tank down and measuring the temperature again. The results from this test are inconclusive. Vacuum had no effect on the set temperature during some tests, and produced as much as a 0.5°C change in others. Any vacuum effect was probably directly related to how well sections of the assembly were mated and how clean the contact surfaces were.

Laboratory tests indicated that the controlled temperature was repeatable from day to day; no measurable change occurred.

Tests were also performed to determine the effect of radical ambient temperature change on the controlled temperature. Preliminary data showed that the controlled temperature changed 1°C for a 40 °C ambient temperature change. The ambient temperatures were -11 °C to +29°C (the expected maximum and minimum ambient temperature at White Sands Missile Range at the time of launch).

By measuring the wave length of the transmission peak of the filter the actual temperature of the quartz plates inside the filter could be determined to ±0.5°C. Tests showed that during the cooling procedure the quartz plates reached their temperatures 3 minutes later than the aluminum tube of the filter. A minimum time of 30 minutes was required from the start of the cooling operation to bring down the optics from room temperature (24°C) to operating temperature (13.7°C).

Flight Data

On all three rocket flights, two temperature probes were mounted on the top portion of the aluminum tube surrounding the quartz plates, one at each end. The analog outputs of these probes were fed into a commutated analog telemetry channel, and read out 2.5 times per second during the entire flight. On the third rocket an additional temperature probe was mounted on the rear portion of the filter, the analog output of this probe being read out by a 10-bit analog-to-digital converter.

Data from the analog telemetry read-outs are such that the built-in error could be as high as ±0.1 V (0-5 V full scale). Thus the temperature data on these channels are not absolute values, inasmuch as an error of ±1 °C could be present.

Data from the first rocket must be analyzed separately, for on this flight the instrument was pointed at the sun for approximately 260 seconds, while the second flight had zero pointing time and the third flight had 23 seconds pointing time.

Figure 5 shows the flight temperature data for both the front and rear of the filter on the first (4.49) and the third (4.145) flights (each point represents an average of twenty commutated read-outs). On the first flight, temperature at the rear portion of the filter remained stable ±0.05°C throughout the flight, but the temperature at the front portion of the filter showed a gradual rise to a maximum deviation of 0.5°C from the set temperature during the last 50% of the flight. This temperature rise was due to solar radiation absorbed by an interference filter mounted in front of the optical filter. However, as was pointed out earlier, the temperature sensitive quartz plates had a time lag of three minutes in reaching any given temperature. There is no reason to believe that the quartz plates were affected by this temperature rise. On the last two flights, the temperature at both ends of the filter remained stable throughout the flights owing to insufficient pointing time for solar radiation to heat up the filter.

Flight data also showed that the temperature was higher at the beginning of all three flights and slowly dropped down to the "set" temperature at sustainer engine burnout. This had two

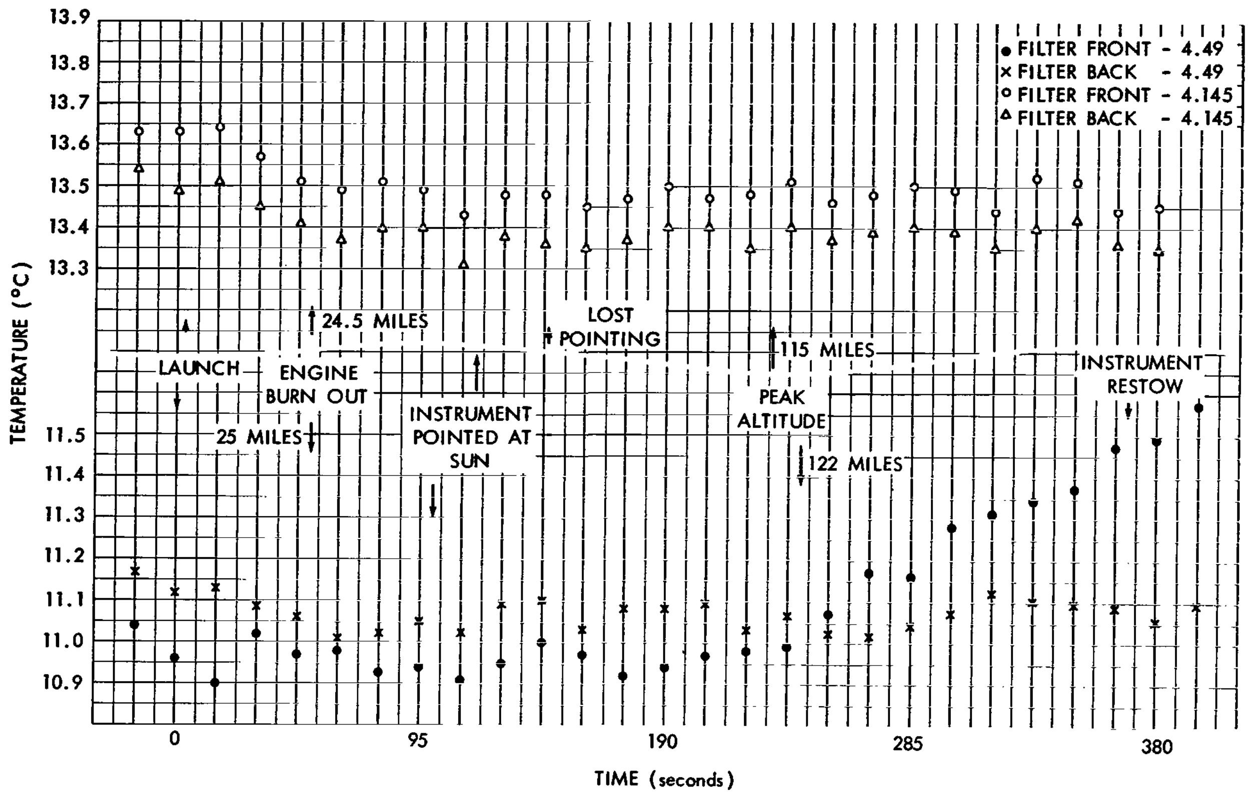

Figure 5—Flight temperature data from first and third flights.

causes. First, the temperature control unit was turned on at T-2 hours to give the optical filter ample time to reach the desired temperature. During this period (T-2 hours to T-0) the noise level (60 cps) was very high at monitor points, due to 110 V and 440 V power lines running side by side with unshielded signal lines in the same trench from block house to launch pad—a decidedly unhappy arrangement. This noise in the ground cables actually raised the set temperature. The second cause for the higher temperature read-out at the beginning was ionization created when the rocket engine was burning. This ionization attenuated the telemetry signal, thus making the noise in the telemetry channels more prominent and bringing about an apparent rise in the set temperature.

The small temperature gradient (0.08°C) between the front and rear portions of the filter was probably due to uneven temperature distribution in the temperature-controlled surface resulting from differences in heat transfer efficiency of the Peltier heat pumps. Imperfect thermal contacts between heat pumps and the temperature-controlled surface could also cause a temperature gradient.

It should be noted that there were no temperature changes due to vacuum effect on any of the three rocket flights, although these flights were sufficiently long for vacuum effect to be noticeable if any was present.

Digital temperature data (not shown) on the third flight confirm the analog data. The fluctuation of ±0.05°C from sustainer engine burnout to the end of the flight was indeed real. There is no obvious explanation as to why this fluctuation was over three times greater than during laboratory tests.

CONCLUSIONS

As stated at the outset, the optical filter used could tolerate a maximum temperature change of ±1°C. Nevertheless, it was decided to use this opportunity for a design exercise to see what degree of accuracy could be achieved in a reasonable amount of time.

The performance of the temperature control unit, both in the laboratory and during flight, may be summarized by the following:

(1) Under normal laboratory conditions, the maximum variations from the set temperature at any given point in the optical filter were measured to be ±0.015°C; however, during the flights, fluctuations of three times this value were measured.

(2) An average temperature gradient of 0.08°C between the front and rear portions of the filter was noticed during the flights.

(3) The unit was not affected by vacuum when all contacting surfaces were well-mated and cleaned.

(4) The flight unit passed all preflight shock and vibration qualification tests, and survived launch and recovery in all three flights.

There is no doubt that minor changes in the electronics and mechanical design would result in improved control accuracy.

In future applications, when birefringent filters with narrower band-passes are used, the temperature control requirement of the filters will become even more critical. The temperature control unit described here is particularly suitable for this application. Especially when the problems (noise) connected with the launch procedures are solved, very accurate temperature control will be possible both before launch as well as during the flight.

ACKNOWLEDGMENTS

The authors are grateful to Mr. Robert Jensen, President of Materials Electronic Products Corporation, who contributed his expert knowledge to the application, modification and mounting of the Peltier heat pumps. We also wish to thank Mr. Kennard Saffer and Mr. Richard Ugainsky of the Solar Physics Branch for the mechanical design, drawings and supervision of the production of the mechanical unit. Mr. Gary Harris of the Solar Physics Branch helped in making detailed measurements and temperature probe calibrations during the development of the temperature control unit.

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Technical information generated in connection with a NASA contract or grant and released under NASA auspices.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

TECHNICAL REPRINTS: Information derived from NASA activities and initially published in the form of journal articles.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities but not necessarily reporting the results of individual NASA-programmed scientific efforts. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546