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DEVELOPMENT OF FLIGHT ALUMINUM OXIDE WATER VAPOR SENSOR SYSTEMS--ETC(U)
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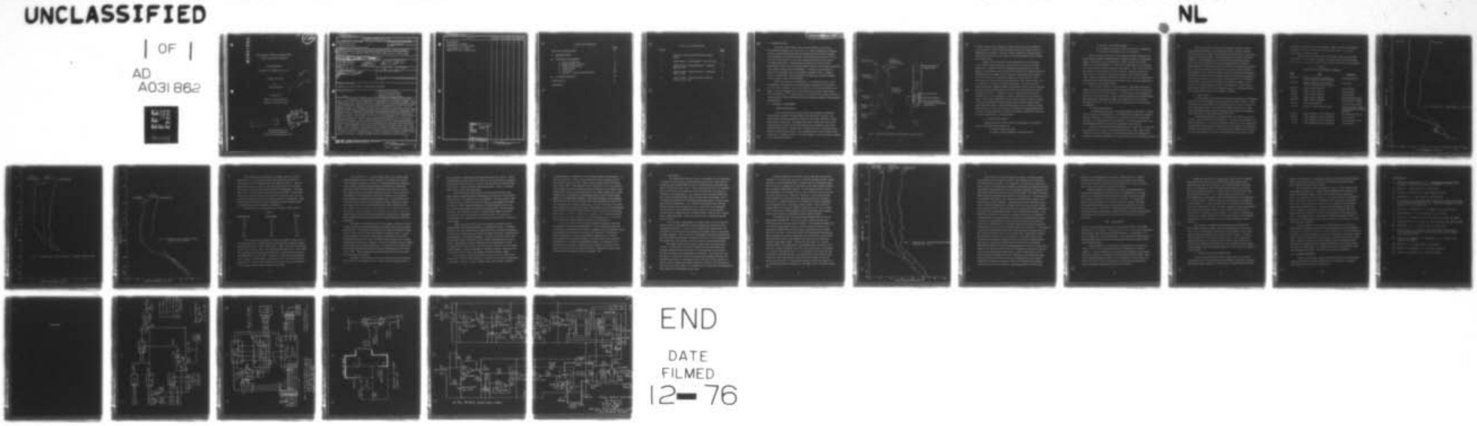

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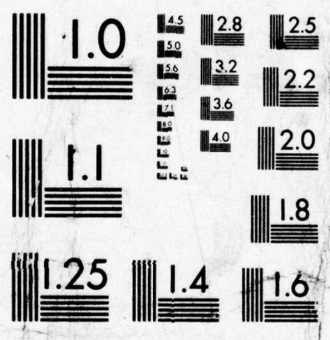

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Development of Flight Aluminum Oxide Water Vapor Sensor Systems

FINAL REPORT

Contract No. N00014-75-C-1114

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13. ABSTRACT

Stratospheric humidity profiles were obtained with "heated" Al_2O_3 type water vapor sensors whose temperature during flight was maintained constant. Additional profiles were obtained with newer, integrated circuit type Aquamax™ sensors. The "heated" sensor provided frost point data which generally increased with stratospheric altitude, in agreement with most earlier unheated sensor data. It is concluded that this type of humidity profile cannot result from ambient temperature effects upon the sensor. "Heated" sensor flight requirements resulted in excessively rapid descent rates and are thus incompatible with conventional radiosonde deployment. Aquamax sensors, which exhibit at least an order of magnitude more rapid response time in laboratory test systems, were flown unheated and data were corrected for ambient temperature. Some resultant profile data obtained during a much slower descent were almost identical with the "heated" sensor data, providing additional evidence that the Al_2O_3 type sensor has an adequately rapid response time for balloon flights. Other Aquamax sensor profile data indicated a constant mixing ratio stratosphere which is unusual but has been observed earlier for Al_2O_3 sensor data. Data indicate that stratospheric profiles are variable and may be related to stratospheric circulatory patterns. Aquamax sensors, when developed in a heated version, should provide a means for convenient deployment with conventional radiosondes.

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	ROLE	WT	ROLE	WT	ROLE	WT
Stratosphere						
Stratospheric humidity						
Stratospheric humidity profile						
Al_2O_3 water vapor sensor						
Aquamax^{TM} water vapor sensor						

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I. INTRODUCTION

The Al_2O_3 water vapor sensor has been utilized for numerous meteorological applications, (see refs. 1-5). Most stratospheric humidity-altitude profile data obtained with such sensors tend to generally parallel the stratospheric temperature profile despite numerous instances of local segments of the profile for which the frost point and temperature move in opposite directions. Nevertheless criticisms have arisen that the parallelism results from temperature effects upon the sensor rather than from real changes in H_2O vapor concentration. To negate such criticisms, a method of maintaining sensor temperature constant, termed a "heated" sensor, was devised. This report presents experience and data obtained with such heated sensor balloon flights.

Numerous obstacles and difficulties, to be discussed below, were encountered. Nevertheless much information regarding the behaviours of the water vapor detection system was obtained as well as restrictions as to usage. At present Panametrics has developed a new water vapor sensor, termed the Aquamax^{TM}, which promises to obviate all the problems hitherto encountered and which represents at least an order of magnitude improvement in performance.

II. TECHNICAL DISCUSSION

1. Sensor Construction

The construction of the Al_2O_3 sensor has evolved as methods of improving performance characteristics were developed. However, improvements could not generally be achieved without some sacrifice in other performance behaviours. All Al_2O_3 water vapor sensor used were of the ruggedized type (Type A) which may exhibit some dependence upon stratospheric temperatures. Whether this is indeed the case, a mounting surface, depicted schematically in Fig. 1, was designed which would maintain sensor temperature constant at + 25°C. For some flights, two sensors were installed on the same heated mount.

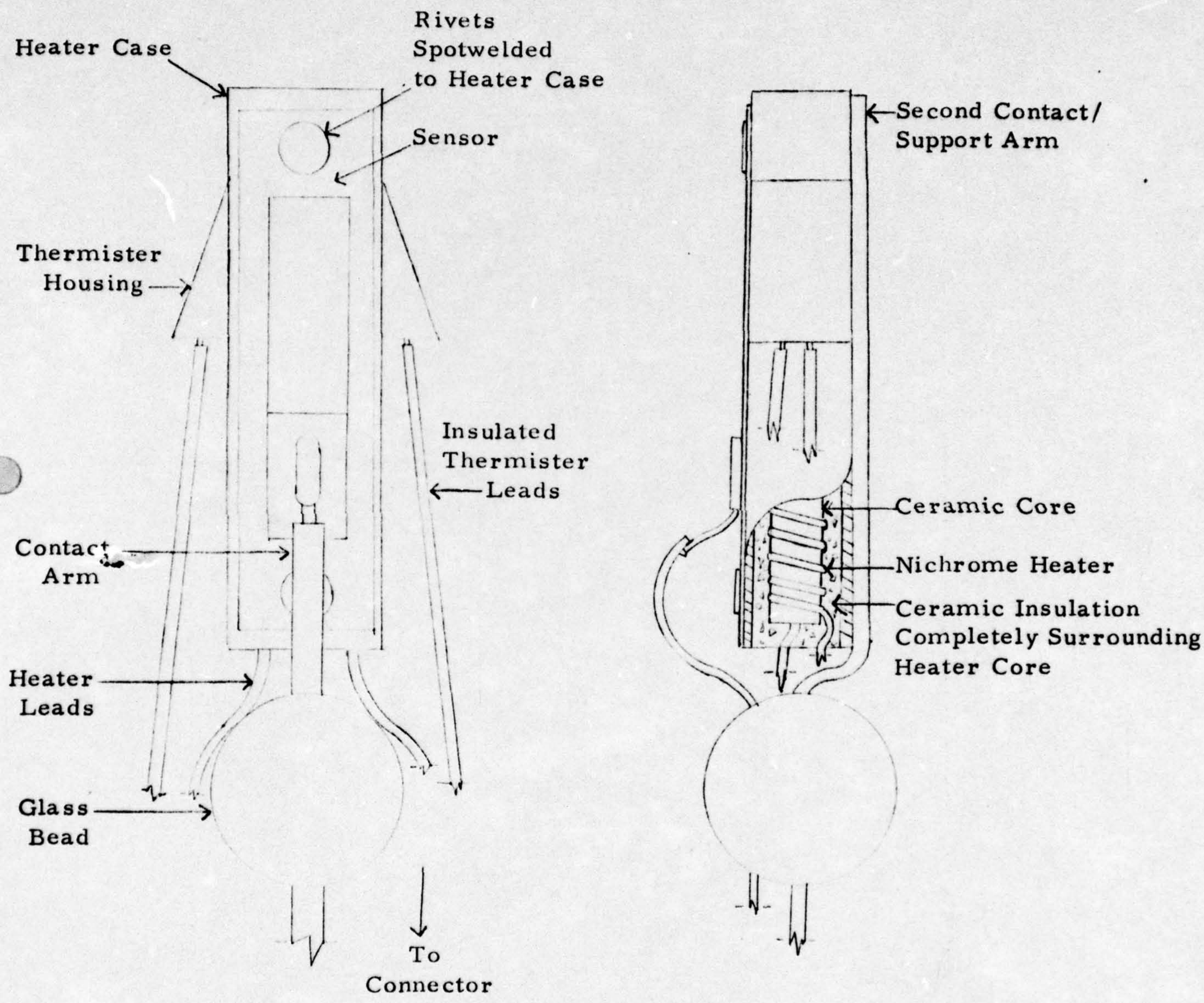

Fig. 1. Schematic drawing of heated sensor and its mount.

Another variant of this ruggedized sensor (Type B) was also employed in this program. Type B sensors display more rapid response times in laboratory test systems. However, under conditions of meteorological flight Type A sensor has been shown to exhibit adequately rapid response times (see Ref. 6).

Sensors were calibrated at room temperature in a flowing gas stream whose dew/frost point was measured by a cooled-mirror type hygrometer. Sensors were also calibrated, particularly at low frost points, in a specially constructed cell which could be evacuated and sealed. Distilled water was added to the cell prior to evacuation and the entire cell was immersed in a liquid bath capable of being cooled to $-115^{\circ}C$. Provision was made for electrical connections to the sensor, heater, and to temperature control and readout thermistors. During calibration, heater power was supplied through a temperature control circuit, identical with that utilized during flight (see below), which maintained the sensor mount at $25 \pm 0.5^{\circ}C$. Calibrations were conducted by assuring equilibration of the sensor impedance reading with the water vapor environment. Under these conditions the water vapor pressure inside the sealed cell was established by the bath temperature and thus provided a frost point calibration datum. Such calibration data could be obtained at frost points as low as -90 to $-95^{\circ}C$ and were extended up to approximately $0^{\circ}C$ in order to verify that they coincided with previous calibrations conducted at room temperature in a flowing stream.

2. Balloon Flight Circuitry.

Standard Viz Corp. Model 1292-401 radiosondes were utilized and were modified by the addition of

a) Sensor readout circuitry
b) Sensor mount temperature control circuitry

c) 12 VDC, 4.5 AH battery supply

d) 25 ft cable at the end of which the sensor was suspended

e) Circuitry for readout of one or two sensors.

Sensor readout circuitry was of the pulse repetition frequency type which has been used by Panametrics for a number of years for radiosonde flights. Schematics for the temperature control circuitry and battery supply are shown in Appendix A. Also shown in Appendix A is a schematic of the circuit used to permit readout of two sensors. This circuit switched the signal being monitored on each space between segments of the baroswitch 4 secs. after initial contact to each space of the baroswitch was made. Either an ambient temperature sensor or one of the two hygrometers installed could be observed during the initial 4 secs. The other hygrometer was monitored on the segment itself.

Because these additions to the radiosonde, particularly the battery supply, increased the payload weight to approximately 9-10 lbs, excessively rapid descent rates were encountered. Various methods of decreasing the descent rate were attempted. These included specially purchased parachutes, other parachutes obtained from ONR, and a descent valve described by Mastenbrook (Ref. 7). The circuit used to activate this valve is also given in Appendix A.

3. Flight Configurations.

The payload consisted of a Viz Model 1292-401 radiosonde, modified with the circuitry discussed above. The 12 VDC power supply was strapped atop the radiosonde. A 25 foot cable, at the end of which the sensor was attached, was suspended below the radiosonde. The entire payload was suspended approximately 100 ft below the parachute and/or balloon.

Because the unmodified Viz radiosonde has a weight of 2-3 lbs whereas the payload was 9-10 lbs, a special balloon, Kaysam Corp. Model 120D, 1600 gm, was used. Experience showed that this balloon had adequate lift capability and pressure-altitudes in excess of 20 mb were consistently achieved.

The major problem encountered during this program was the excessively rapid descent rate already mentioned. Descent humidity data are required to obtain sensor readings uncontaminated by H_2O vapor present in the balloon wake. Several attempts were made to solve this problem. These included use of two and/or three paper parachutes, both in series and parallel, the afore-mentioned valve described by Mastenbrook (7), a parachute purchased from Strong Enterprises, Quincy, Mass. and nylon parachutes obtained courtesy of the ONR Field Office, Minneapolis, Minn. None successfully solved the rapid descent problem. Although this problem could undoubtedly be solved by more sophisticated ballooning techniques, the normal operating procedures of the Portland, Maine Weather Bureau launch facility, from which all flights were conducted, were already being stretched well beyond their normal limits. Most recent flights with the new Aquamax sensor, to be discussed below, have rendered these descent rate problems obsolete.

4. Flight Results.

Initial flights were conducted principally to determine the adequacy of the heater power supply and the temperature control circuitry. It was found that the average battery power required was 6.3 W at 11 V which included dissipation losses in the control circuitry and the 25 foot cable. The entire flight required about 1.2 ampere-hours which was adequate to control the sensor mount temperature at $25 \pm 3^{\circ}C$.

Subsequent flights generally suffered from the rapid descent rate problem, which had two-fold consequences. The first, and generally overriding consequence, was that the baroswitch contact moved so rapidly from one position to another that the dwell-time at each position was insufficient to obtain an accurate frequency reading. Secondly, insufficient time might not have been available for sensor equilibration with the ambient even if accurate sensor readings could be obtained. Other problems encountered included sensor failure, particularly with Type B sensors, electronic malfunction, and launch failure.

Flights conducted are listed in Table 1 along with notes regarding the outcome. As is noted in the table, only three flights provided useable descent data, two of which involved the new Aquamax sensor, flown unheated.

Table 1.

Heated Sensor Balloon Flights Conducted

Date	Type	Comment
10/30/74	flight to determine temperature control and heater power adequacy.	electronic failure
10/30/74	flight to determine temperature control and heater power adequacy.	successful
4/10/75	single sensor (Type B).	sensor failure
4/10/75	single sensor (Type B).	sensor failure
7/10/75	single sensor (Type A).	launch failure
7/10/75	single sensor (Type A).	successful (see Fig. 2)
10/1/75	single sensor (Type B).	descent rate too rapid
10/1/75	dual sensor (Type A).	descent rate too rapid
3-4/76	dual sensor (one Aquamax type)	numerous sensor failures during calibration-flights abandoned.
5/25/76	single Aquamax sensor (unheated)	successful (see Fig. 3)
5/25/76	single Aquamax sensor (unheated)	sensor failure
6/9/76	single Aquamax sensor (unheated)	successful (see Fig. 4)
6/9/76	single Aquamaz sensor (unheated)	sensor failure

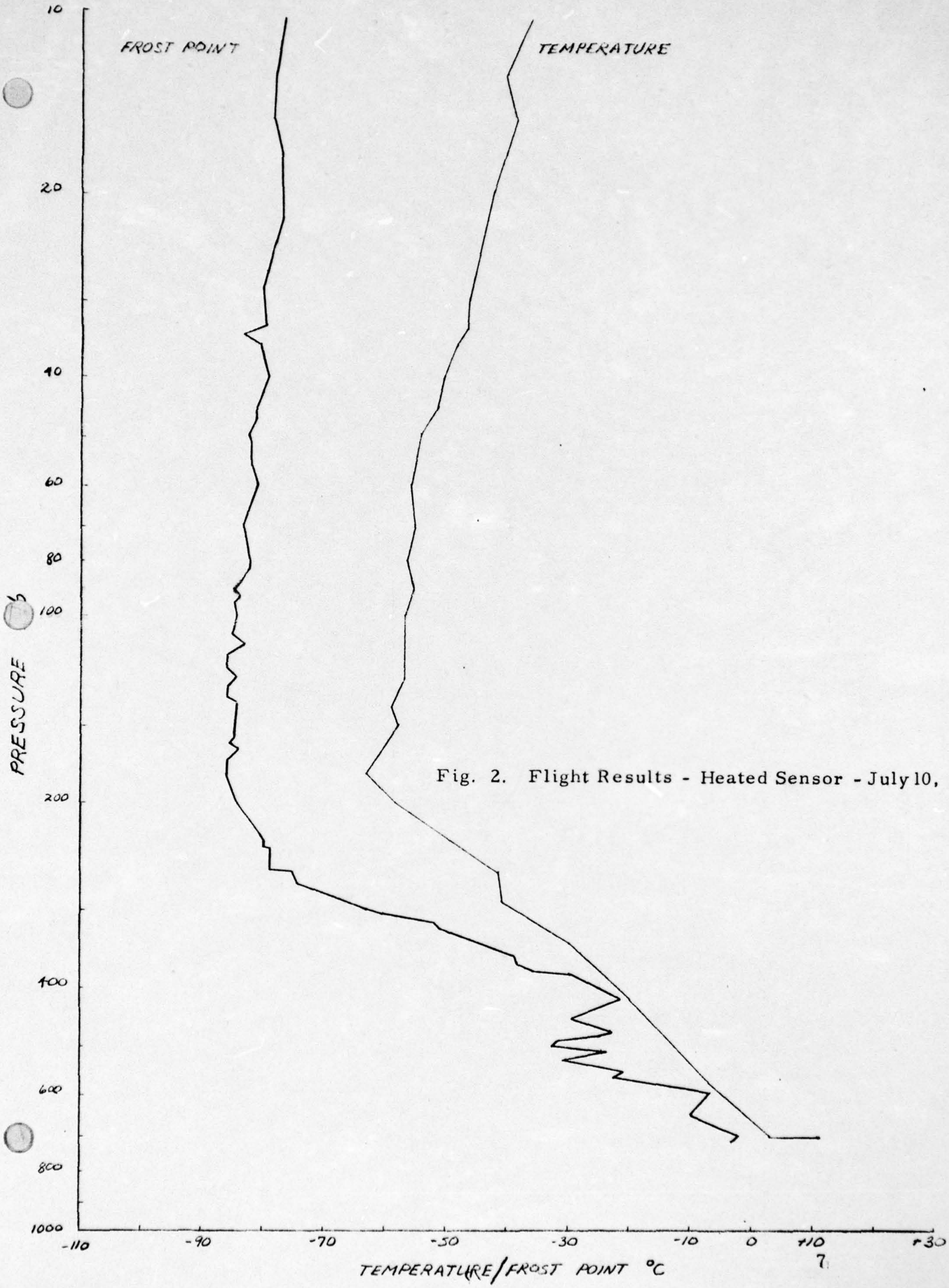

Fig. 2. Flight Results - Heated Sensor - July 10, 1975.

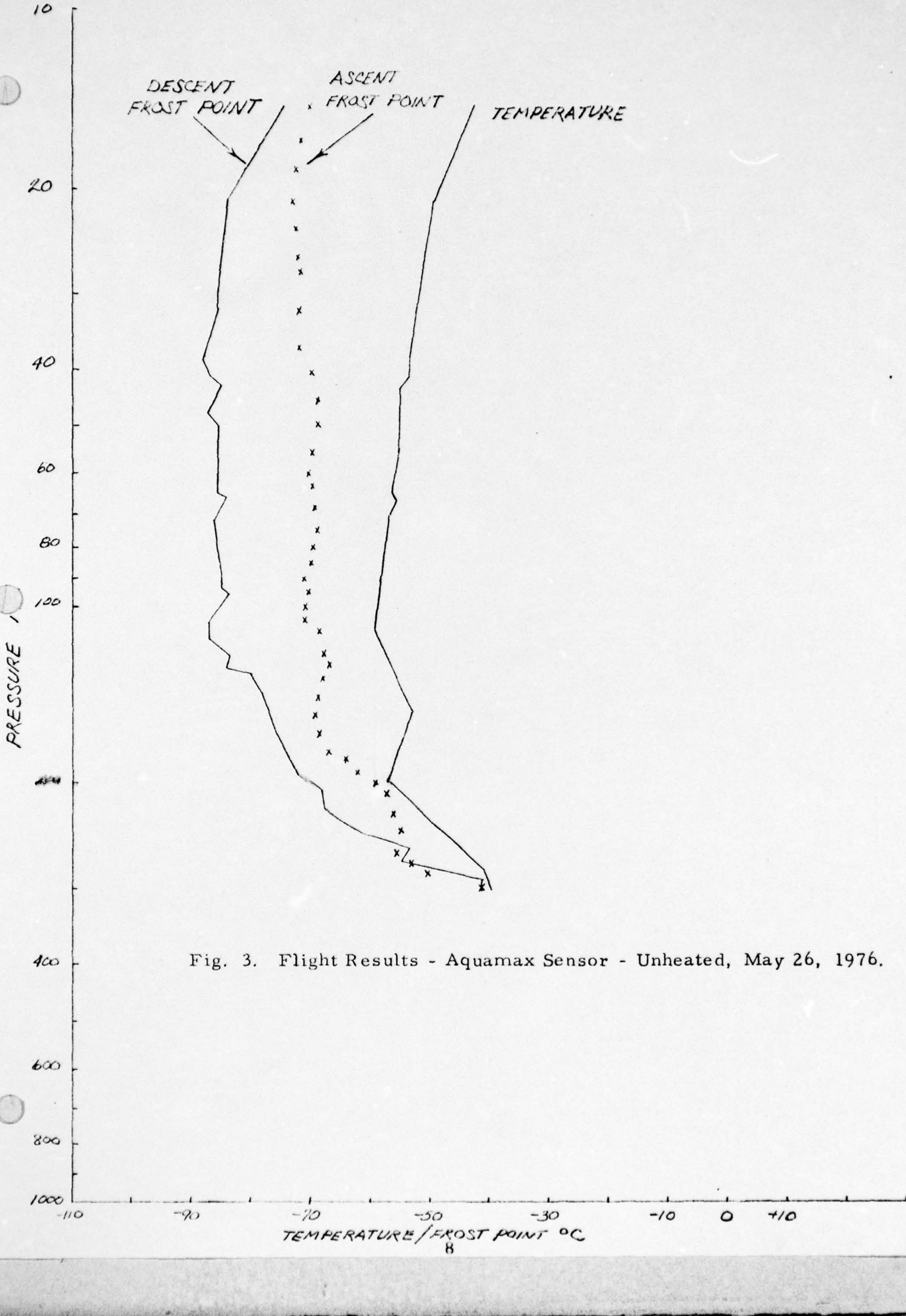

Fig. 3. Flight Results - Aquamax Sensor - Unheated, May 26, 1976.

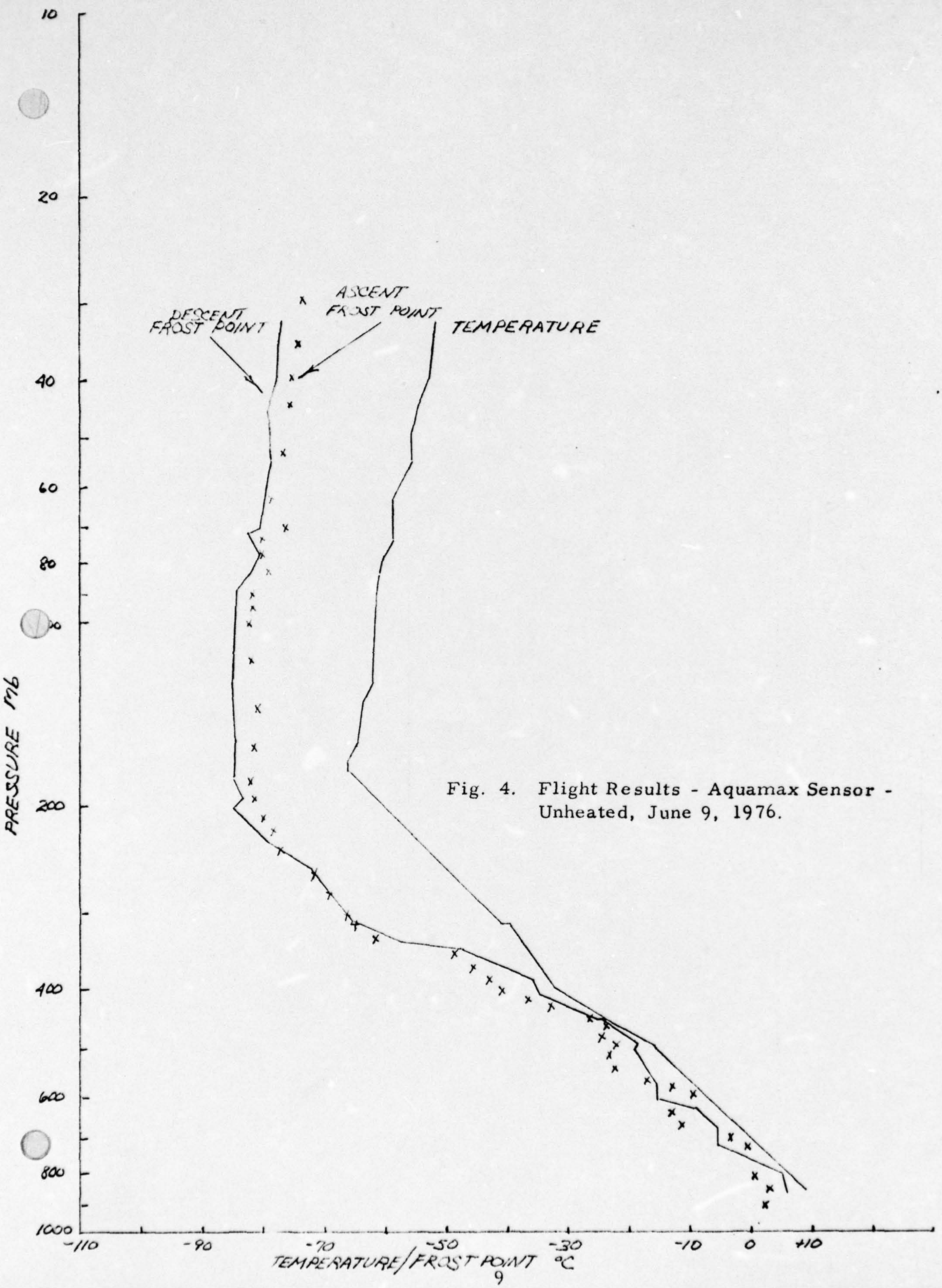

Fig. 4. Flight Results - Aquamax Sensor - Unheated, June 9, 1976.

The humidity profile obtained in the flight of July 10, 1975 is shown in Fig. 2. Descent frost point data show patterns similar to most previous flight results obtained with unheated sensors. The ambient temperature is parallel to the frost point data to the extent that both show decreasing values upon descent to the tropopause. However, the rate of decrease is much less for the frost point data. Small-scale structure is observed during descent which, in several cases, was opposite in direction to that of the ambient temperature fluctuations. Much structure was observed in the mid-tropopause region indicating rapid response times at the frost points encountered.

Selected values of mixing ratios are shown in Table 2 below:

Table 2.

Altitude, mb	Frost Point	ppm_w
10.3	-77	52
15.3	79	27
29	80	12
33	80	10
100	85	1.5
180	86	0.7

If the maximum stratospheric mixing ratio (MR) is taken as 10, it is seen that descent to about 30 mb was required before sufficient sensor drying occurs to give a permissable value. Time for descent from balloon burst to 30 mb was 2.3 min. The tropopause MR appears to be lower than most accepted values but not unreasonably so. Some IR data have given tropopause MR's as low as this. Moreover, if the MR at the tropopause were 1 ppm_w, the frost point would have been -84^o, well within the estimated error. However, the estimated error would not have permitted an 80^oC frost point which would correspond to 2 ppm_w.

In the fall of 1975, it became evident that a more sophisticated balloon launching system would be required if acceptably low descent rates were to be achieved. However, simultaneously the new Aquamax sensor became available and was being characterized as exhibiting much more rapid response times in laboratory test systems than had been observed with any previous Al_2O_3-type sensor. For purposes of stratospheric moisture detection, this new Aquamax sensor offerred many advantages, including a much smaller size. It was therefore decided to attempt to make an intercomparison flight using both an older-type Al_2O_3 sensor and a newer Aquamax type, both positioned on the same mount. Numerous attempts to calibrate such a dual sensor in the laboratory resulted in Aquamax sensor failure in all cases. It was concluded that the heated sensor mount previously utilized was incompatible with the Aquamax sensor and attempts at an intercomparison flight were abandoned.

The flights of 5/25/76 and 6/9/76, the results of which are shown in Figs. 3 and 4, were therefore flown to ascertain whether the excellent performance demonstrated in laboratory tests would be exhibited in flight as well. Since sensors could not be placed on heated mounts, a conventional radiosonde was flown modified only by the inclusion of a sensor impedance measurement circuit. Relatively slow descent rates resulted, making data retrieval much simpler. Because the Aquamax sensor exhibits a dependence upon ambient temperature, the sensors were calibrated not only at room temperature but also at ambient temperatures in the range -40 to -60°C. Room temperature calibration data were then corrected for the ambient temperature.

The flight results shown in Fig. 3 are unusual in that descent data do not follow the temperature trend. In fact, as a first approximation, the frost point is substantially invariant from about 20 to 120 mb. Closer examination shows that, from 40 to 120 mbs, the data indicate an approximately constant MR of 2 ppm_w. Ascent data for pressure-altitudes below 350 mbs were uncorrected for ambient temperature. Hence, the discontinuity in the ascent frost-point data.

The flight results shown in Fig. 4 more closely resemble most flight results previously obtained with Al_2O_3 type sensors in that the frost point increases with altitude in the stratosphere. The data indicate a MR of about 10 ppm_w at 40 mb and about 0.9 ppm_w at the tropopause located at 180 mbs. Such results provided by an unheated Aquamax sensor are very close to those obtained with the heated Al_2O_3 Type A sensor shown in Fig. 1. These data are, however, unusual in one respect in that the ascent and descent frost points are almost identical. This may have resulted from the comparatively cold tropopause temperature encountered on this flight.

Flight results shown in Fig. 3 and 4 should be regarded as preliminary data indicating the potential of the Aquamax sensor. Calibration and data reduction should be much simplified when a controlled temperature version of the Aquamax sensor becomes available (currently being developed by Panametrics with internal funding). Because of the small sensor size and integral heater construction, power requirements should be much reduced. Calculations indicate a maximum power requirement of about 0.7 watts for the sensor heater and less than 0.9 watts for the entire heater control system. This corresponds to a reduction in power requirement by at least a factor of 7 with a consequent reduction in battery weight.

The Aquamax sensor has markedly improved time-response characteristics which are demonstrable in a laboratory test system at atmospheric pressure. Earlier sensors, although quite rapid in flight, exhibited comparatively slow response at low frost points (FP) in the laboratory. It has been possible to measure and analytically examine Aquamax sensor reading vs time data for step changes in both directions in the FP region from -60 to -80°C. Step changes in FP of only 5°C or less in all portions of this region have been examined as well as changes over the entire range. Although the response characteristics are not simple exponentials, in part because of wall adsorption and desorption effects, some of these effects appear to be analytically separable. This type of analysis gives response times of 10-25 secs for decreasing water vapor pressures and 30-40 secs for increasing water vapor pressure (P_w). It is to be noted that the longer time constant for increasing P_w may be misleading. For the unrealistically large change in FP from -80 to 60°C, the sensor achieves a final reading, within its error band, in a single time constant. These response data are to be compared to time constants for the older Al_2O_3 sensor on the order of 10-20 mins in similar laboratory systems (see also Ref. 7).

It is to be noted in Table 1 that only half the flights launched with the Aquamax sensor provided flight data. It was subsequently found that the circuitry used impressed too large a voltage across the Aquamax sensor, causing numerous sensors to fail even in the laboratory. Modification of the circuitry has corrected this problem. Aquamax sensor failure during flight does not appear therefore to be an inherent sensor problem but rather was a circuitry compatability problem. In retrospect, it is possible that the circuitry caused the sensor failures encountered in the flights of 4/10/75 and in the repeated failure of Aquamax sensors during lab calibrations conducted in March and April, 1976.

5. Discussion

The flight results shown in Fig. 2 are notable in view of numerous criticisms of earlier Al_2O_3 humidity profile descent data. Most data obtained from the Portland, ME launch site had the general characteristics shown in both Figs. 2 and Figs. 4. These characteristics are a) a minimum FP in the vicinity of the tropopause and b) FP (and MR) increasing with altitude into the stratosphere. The criticism most frequently stated was that, since the ambient temperature also increased with altitude, the increasing FP resulted from an unacknowledged dependence of sensor output upon ambient temperature. This criticism arose because the humidity profile measured by the Al_2O_3 was not in accord with the stratospheric moisture profile model postulated by Brewer (8) nor with the general characteristics of Mastenbrook's (9) flight results, obtained with a cooled-mirror type hygrometer, which were stated to be in agreement with the Brewer model.

This criticism cannot apply to the flight results of Fig. 2 since the heated sensor is at substantially constant temperature during the entire stratospheric descent. In spite of the constant sensor temperature, the minimum FP is observed at the tropopause and higher FP's are measured at higher altitudes. This results in a stratospheric humidity profile having the characteristics previously critically attributed to a sensor temperature dependency but, for this flight, the sensor was at constant temperature.

The flight results shown in Fig. 4 likewise have the same characteristics. In this case, the Aquamax sensor has an acknowledged temperature dependence and corrections for this dependence were applied. Yet the same type of humidity profile was obtained. Once again, it is not possible to reconcile the criticism with the results obtained because compensation was made for temperature effects. The data of Fig. 3 provide, of course, further evidence that flight results do not derive from temperature effects since, for this flight, the humidity data do not parallel the temperature. This flight will be discussed further below.

Another criticism (10) of earlier Al_2O_3 flight data has been that response time of the sensor was slow. We have contended (6) that, under conditions of meteorological flight, response time was adequately rapid. This contention is supported by comparison of the flight results of Figs. 2 and 4 which are remarkably similar. Yet the average descent rate in the stratosphere for the flight of Fig. 2 was 7.6 Kft/min whereas that for the flight of Fig. 4 was 2.1 Kft/min. Moreover, because the Aquamax sensor exhibits so much more rapid response times in the laboratory (see above), it would be expected to accentuate any effects attributable to slow response time of the Al_2O_3-Type A sensor. The fact that the flight profiles are so similar despite a difference of more than a factor of 3 in descent rate strongly supports earlier contentions that response times of all sensors are adequately rapid for balloon flights.

The flight in Fig. 3 is unusual in that humidity data show an approximately constant MR. It is not, however, unique because such humidity profiles have been observed before. One example obtained with an unheated Al_2O_3-Type A sensor, is given in Fig. 5 for which an approximately constant MR of about 1 ppm_w was measured in the range from 40 to 300 mbs. In this latter flight, the humidity data did approximately parallel the ambient temperature data so that these flight results did not provide evidence with regard to the absence of a temperature influence upon flight results. The data of Figs. 3 and 5 do, however, provide evidence that stratospheric humidity profiles are variable, not only with respect to absolute level, but, more importantly, with respect to the shape of the profile itself. It is interesting to note that such constant MR humidity profiles have been observed from the Portland, ME launch site only in the spring and fall of the year (flights are not conducted from about Dec. through March because strong winds aloft carry the radiosonde beyond the capability of the GMD receiver to obtain descent data.

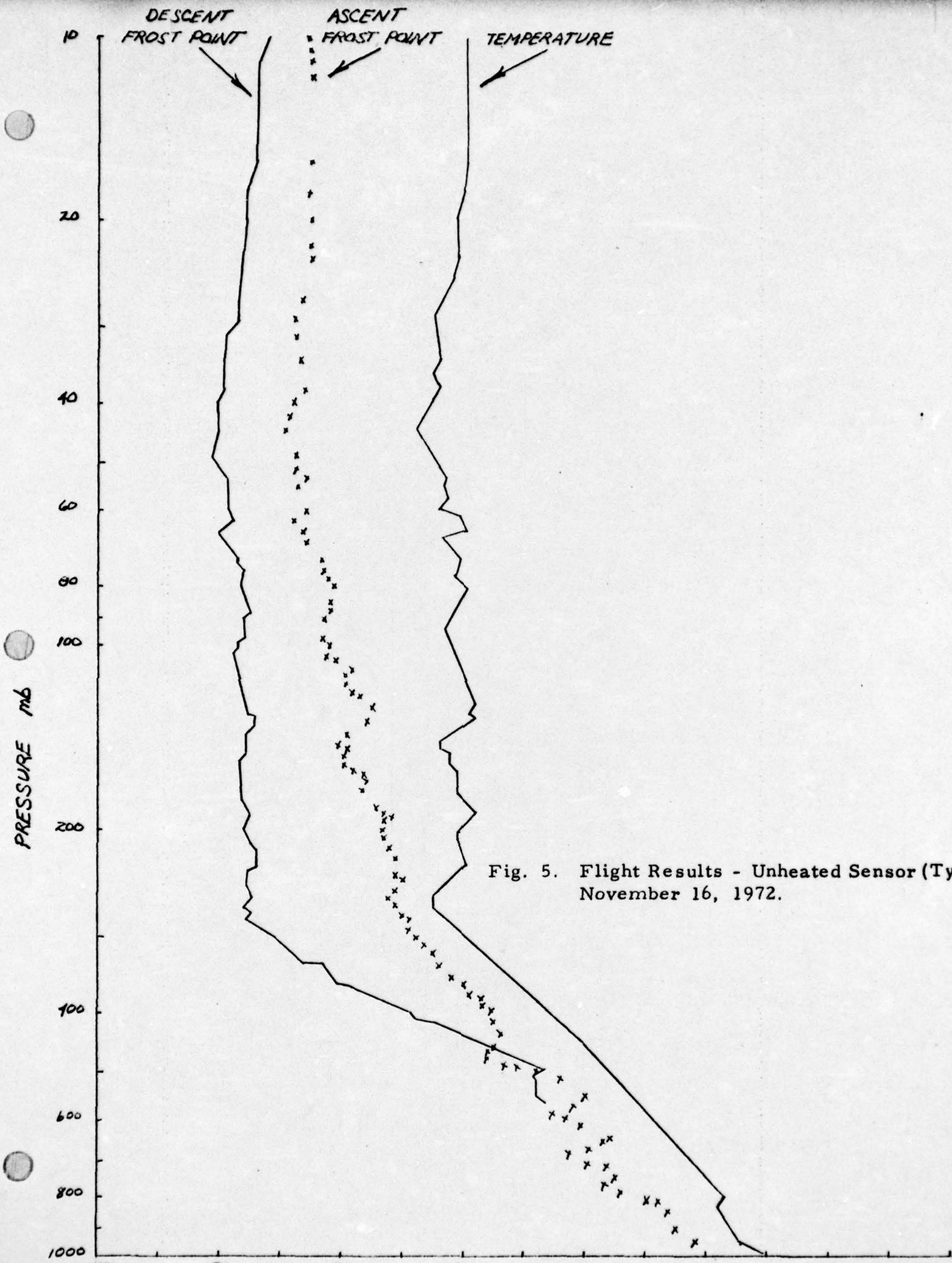

Fig. 5. Flight Results - Unheated Sensor (Type A) November 16, 1972.

The occurrence of these unusual stratospheric humidity profiles may coincide with the relative location of the launch site with respect to the winter polar jet stream. This suggestion is based upon comparison of some recent aircraft flight data obtained at approximate tropopause altitudes and published by Mastenbrook (11) and by Kuhn, Magaziner and Stearns (12). Both papers present P_w data taken aboard the NASA C-141 Kuiper Airborne Observatory during wintertime flights (not simultaneous). The data reported are indexed with respect to the location of the observation relative to the position of the polar jet stream. The data differ in one important respect. Those obtained by Mastenbrook represent the in-situ P_w at aircraft flight altitude whereas those reported by Kuhn et al represent the total integrated P_w above the aircraft flight altitude, termed the H_2O vapor burden. It is difficult to make direct comparisons because the data were not obtained simultaneously on the same flights, and because the Mastenbrook data are referenced to a geographical position whereas the Kuhn et al results are reported in a orthogonalized coordinate system whose axes and origin are determined by the jet stream direction and by the jet maximum. Nevertheless, it appears that the greatest H_2O vapor burden observed by Kuhn et al is on the cyclonic (northern) side of the jet stream and, in particular, slightly in advance (to the east) of the jet maximum. An extensive dry area is shown on the anticyclonic (southern) side of the jet axis although another wet region is shown still further south and west of the jet maximum. Mastenbrook identifies only the geographical location of the jet stream and reports, for numerous traversals of the tropopause discontinuity, that the in-situ P_w increased from about 2 ppm_w on the cyclonic side of the jet stream to values ranging from about 7-20 ppm_w on the anticyclonic side. Kuhn et al note these results reported by Mastenbrook and presumably identify their reported wet region, about 7-8^{o} in latitude and longitude south and west of the jet maximum, with Mastenbrook's increase upon traversal of the tropopause discontinuity. Kuhn etal do not, however, comment upon the absense of any wet in-situ P_w data on the cyclonic, nor any dry in-situ P_w data upon the anticyclonic, side of the jet stream such as they observed for the H_2O vapor burden.

Assuming both sets of data to be correct and representative of atmospheric H_2O vapor concentrations in the neighborhood of a winter polar jet, an apparent discrepancy exists because a high value of H_2O vapor burden represents a high value of in-situ MR. The H_2O vapor burden reported by Kuhn et al is determined by an iterative computer calculation that matches the observed infrared irradiance with a calculated irradiance. The latter, in addition to consideration of instrumental parameters and pressure dependent effects, assumes that the water vapor profile in the column above the aircraft is of the form, given by Smith (13),

$$MR = MR_o (P/P_o)^\lambda$$

where P is the atmospheric pressure, the subscript refers to the flight altitude and λ is a constant. Kuhn et al take $\lambda = 0.3$. This choice represents the H_2O vapor MR as decreasing with altitude (for a constant MR, $\lambda = 0$ and λ is negative for an increasing MR). The iterative calculation involves adjusting MR_o until the observed and calculated irradiances agree within predetermined limits.

One possible way to reconcile the discrepancy is to assume that either $\lambda \neq 0.3$ or that the Smith power law is inoperative in certain situations. These assumptions would permit the stratospheric H_2O vapor profile to show either a constant or an increasing MR with altitude. Kuhn etal do discuss possible divergence and convergence aloft in advance of, and to the rear of, the jet maximum but do not make any adjustment to their calculational procedures because of these effects.

Simplistic analysis would suggest that a MR actually increasing with altitude would result in a calculated H_2O vapor burden which is apparently high. On the other hand, to reconcile Mastenbrook's high P_w on the tropospheric side of the jet stream discontinuity with Kuhn etal's low H_2O vapor burden data would seem to require an actual H_2O vapor profile for which $\lambda > 0.3$. Kuhn and Stearns (14) did use $\lambda = 3$ for tropospheric measurements which indicates that the latter suggestion is, at least, tenable. However, Kuhn and Cox (15) earlier investigated the possibility of $\lambda < 0$ and concluded that, for irradiance data obtained at pressure altitudes of 50 mbs or higher, satisfactory agreement between observed and calculated irradiance values could not be achieved for reasonable values of MR_o if λ was negative. To determine whether this conclusion is equally valid for the aircraft flight altitude of 175-200 mbs would require access to both the raw data and the computer program utilized.

Nevertheless, the apparent discrepancies noted between the observations reported by Kuhn et al and by Mastenbrook in the vicinity of the jet stream does point towards a possible alteration in the stratospheric H_2O vapor profile in the vicinity of the jet stream. Thus the unusual character of the profiles shown in Figs. 3 and 5, obtained in fall and spring when the jet stream aloft may be in the vicinity of the latitude of the Portland, ME launch site, may be related to real changes in stratospheric H_2O vapor profiles induced by winter circulatory patterns at this location.

6. Summary of Balloon Flight Results.

It has been shown that the heated, Al_2O_3 sensor can measure stratospheric level frost points but that the power requirements increase the payload weight sufficiently such that a more sophisticated ballooning system is required than is customarily employed at Weather Bureau stations. Such a system would restrict possible launch locations and would make rocket deployment much more difficult.

The development of the new Aquamax sensor, with its smaller size, much faster response time, greater sensor uniformity and stability, and greatly reduced heater power requirements should obviate many of the problems encountered in this program. This sensor should be suspendable from a standard radiosonde and launchable from almost any conventional launch site. When developed, it will be able to maintain its temperature constant at any desired level. It should also be possible to include the sensor impedance measuring circuitry on the same Aquamax chip, thus eliminating cable capacitance from the total impedance measurement and, hence, improving accuracy. Still another additional advantage is that, if desired, an ambient temperature measurement can be provided by a similar chip at the same location.

Thus the Aquamax sensor should make attainable the goal of conducting semi-synoptic measurements of both tropospheric and stratospheric humidity profiles with comparatively easy to launch and relatively inexpensive equipment. Rocket deployment, because of reduced space and power requirements as well as more rapid response times, should pose many fewer problems. Finally as pertains to meteorological usage, the Aquamax sensor should provide improved aircraft performance because its response time, size, power requirements, etc. should provide more reliable data as well as permitting much greater flexibility with regard to installation.

III. ACKNOWLEDGMENT

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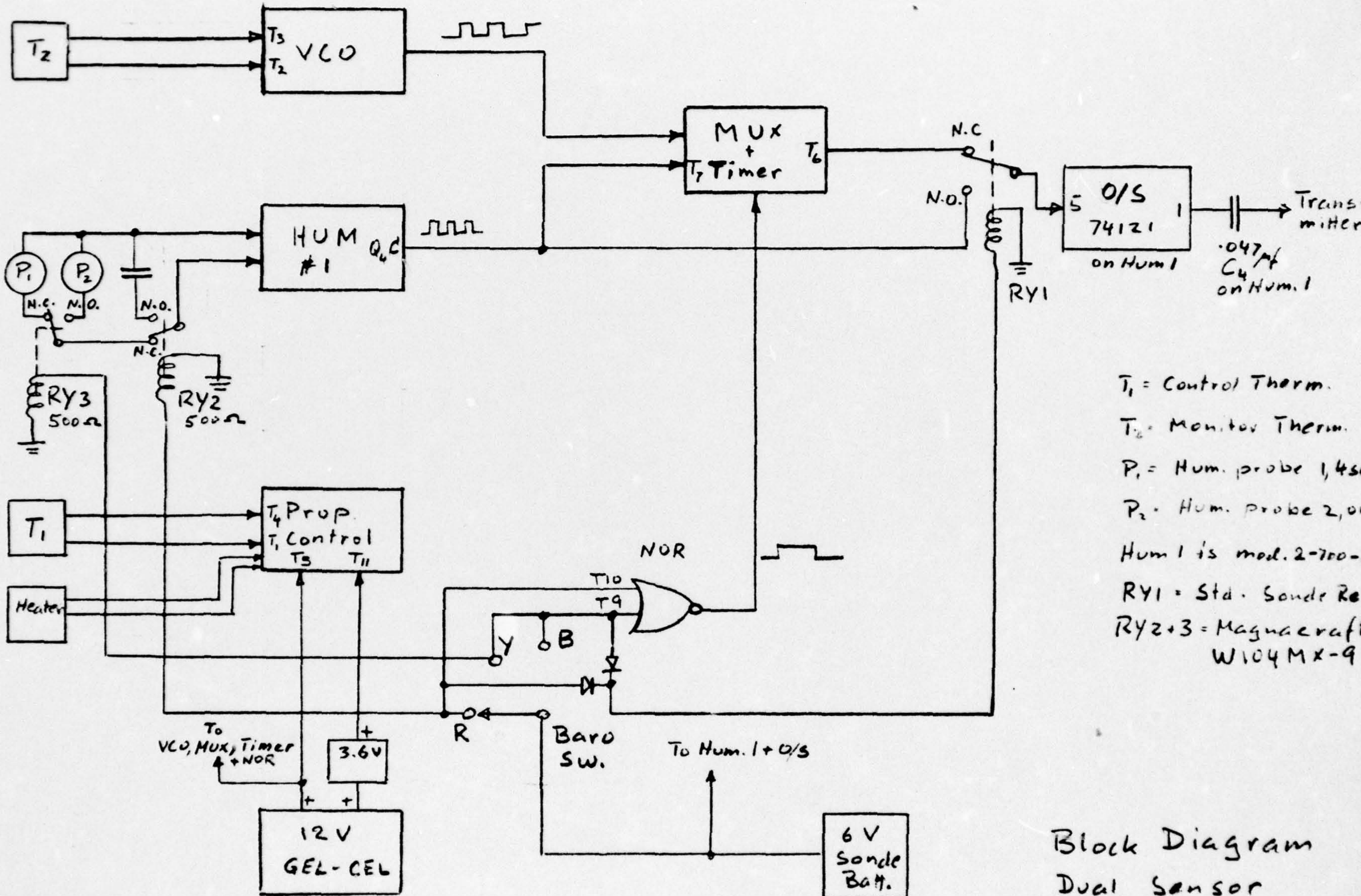
15. Kuhn, P. M. and Cox, S. K., ibid 6, 142 (1967).

APPENDIX A



T_1 = Control Therm.

T_2 = Monitor Therm.

P_1 = Hum. probe 1, 4 sec.

P_2 = Hum. probe 2, on se

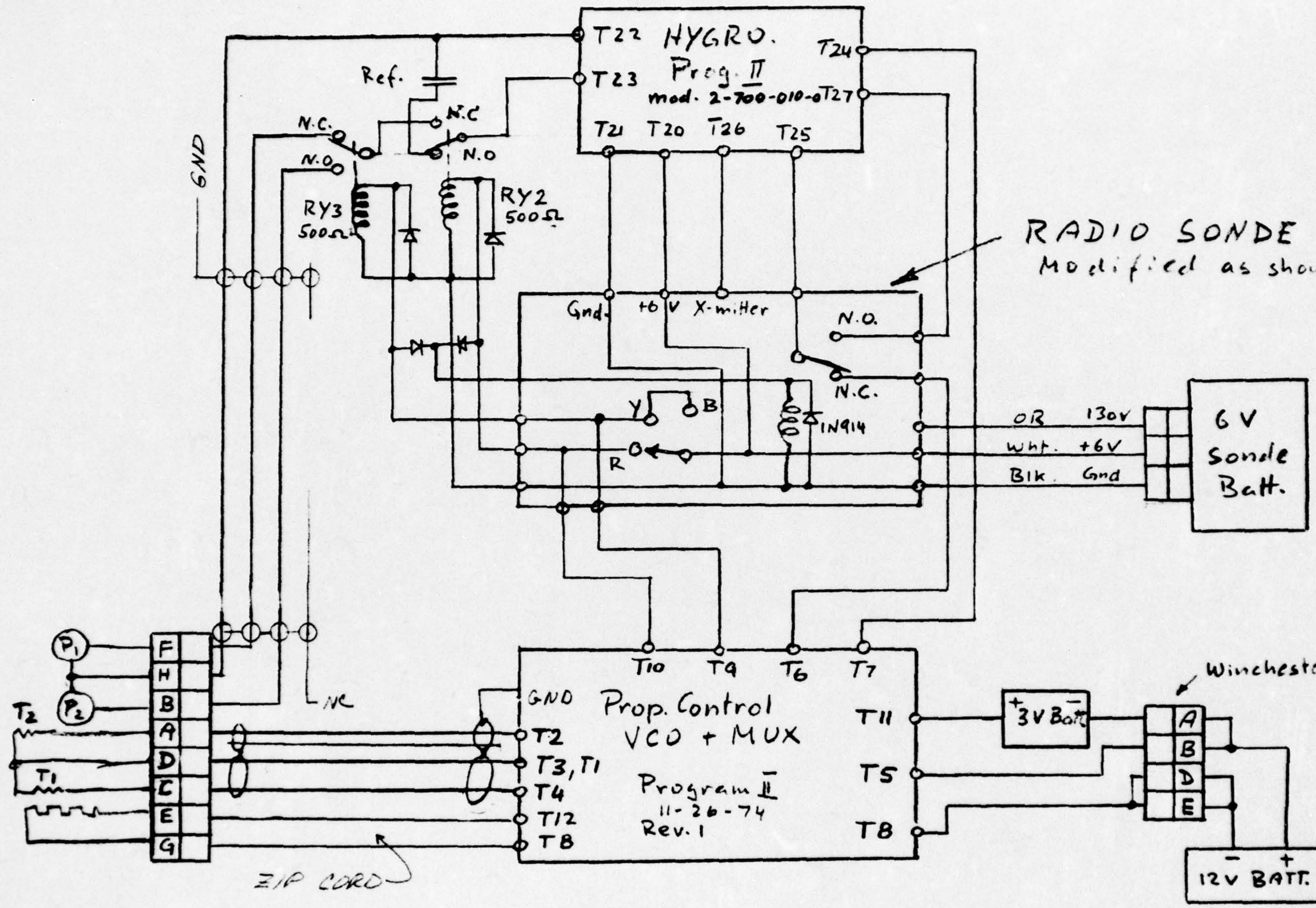
Hum 1 is mod. 2-700-010-

RY1 = Std. Sonde Relay

RY2 + 3 = Magnacraft W104MX-9

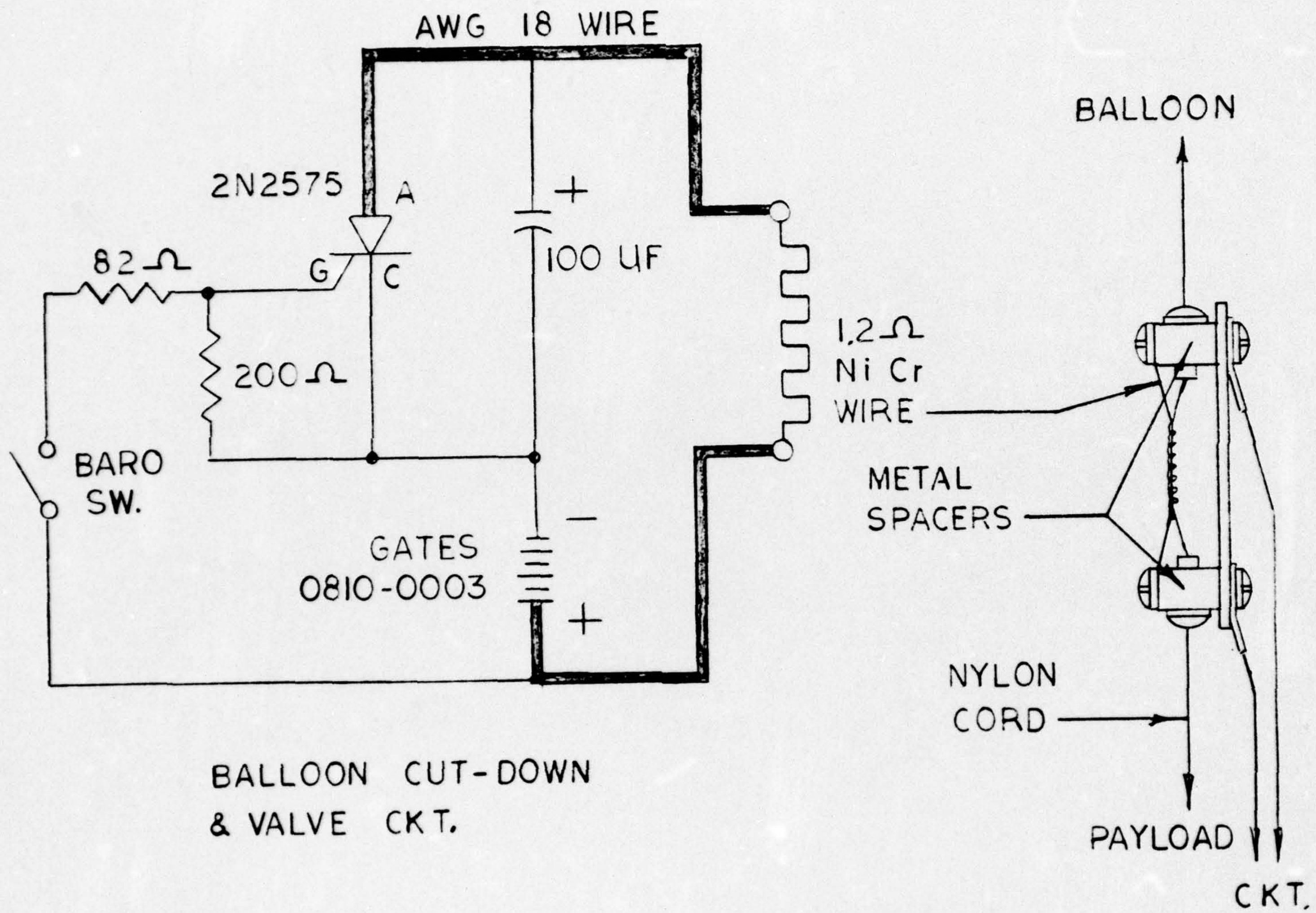
Block Diagram
Dual Sensor
Prog. II

8-13-75 JW

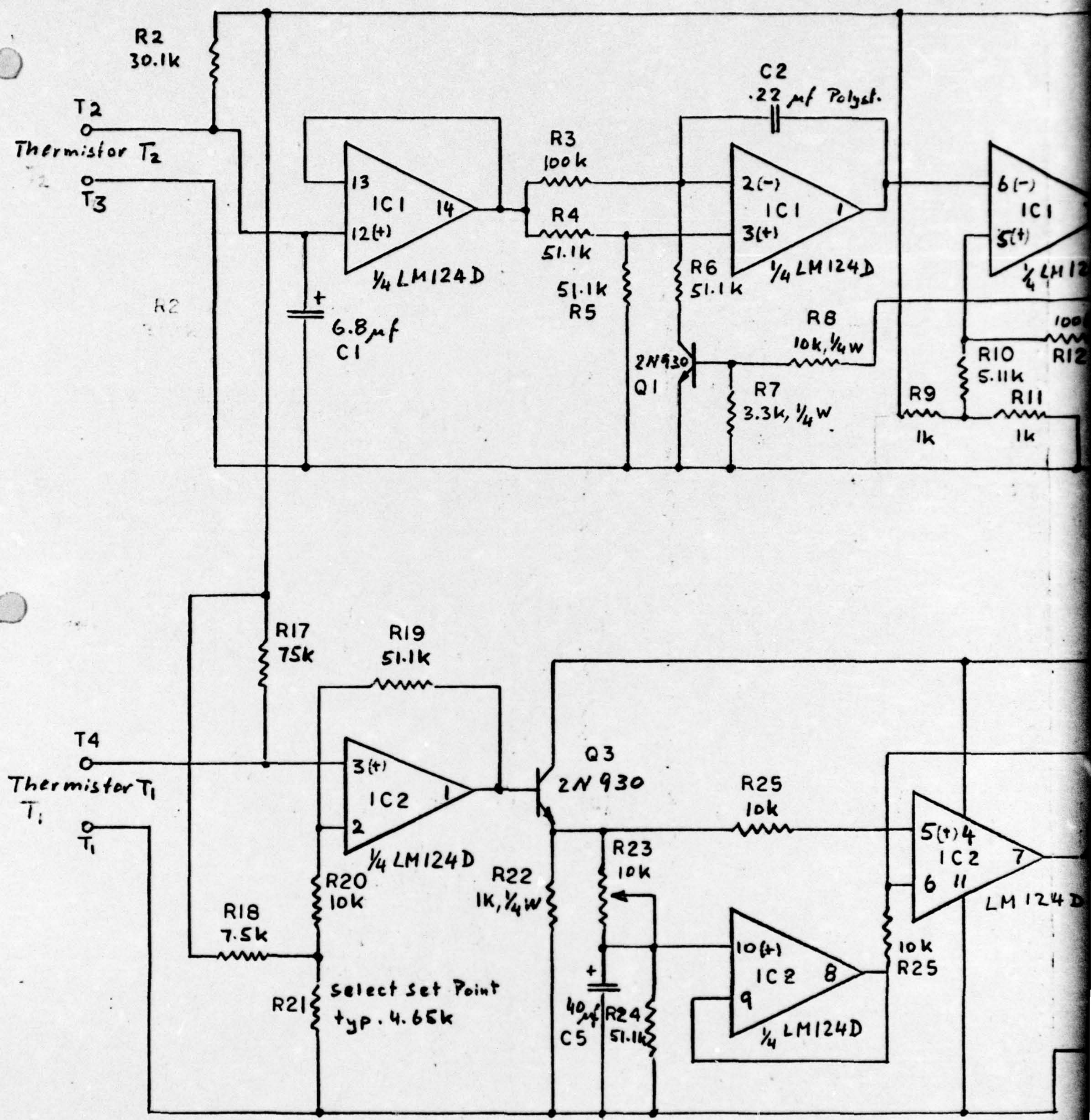


Note: Except for pin B this connector is compatible with the "Cable for LAB Control". Pin B is grounded in "Control Box". See diagram of Cable for LAB CONTROL

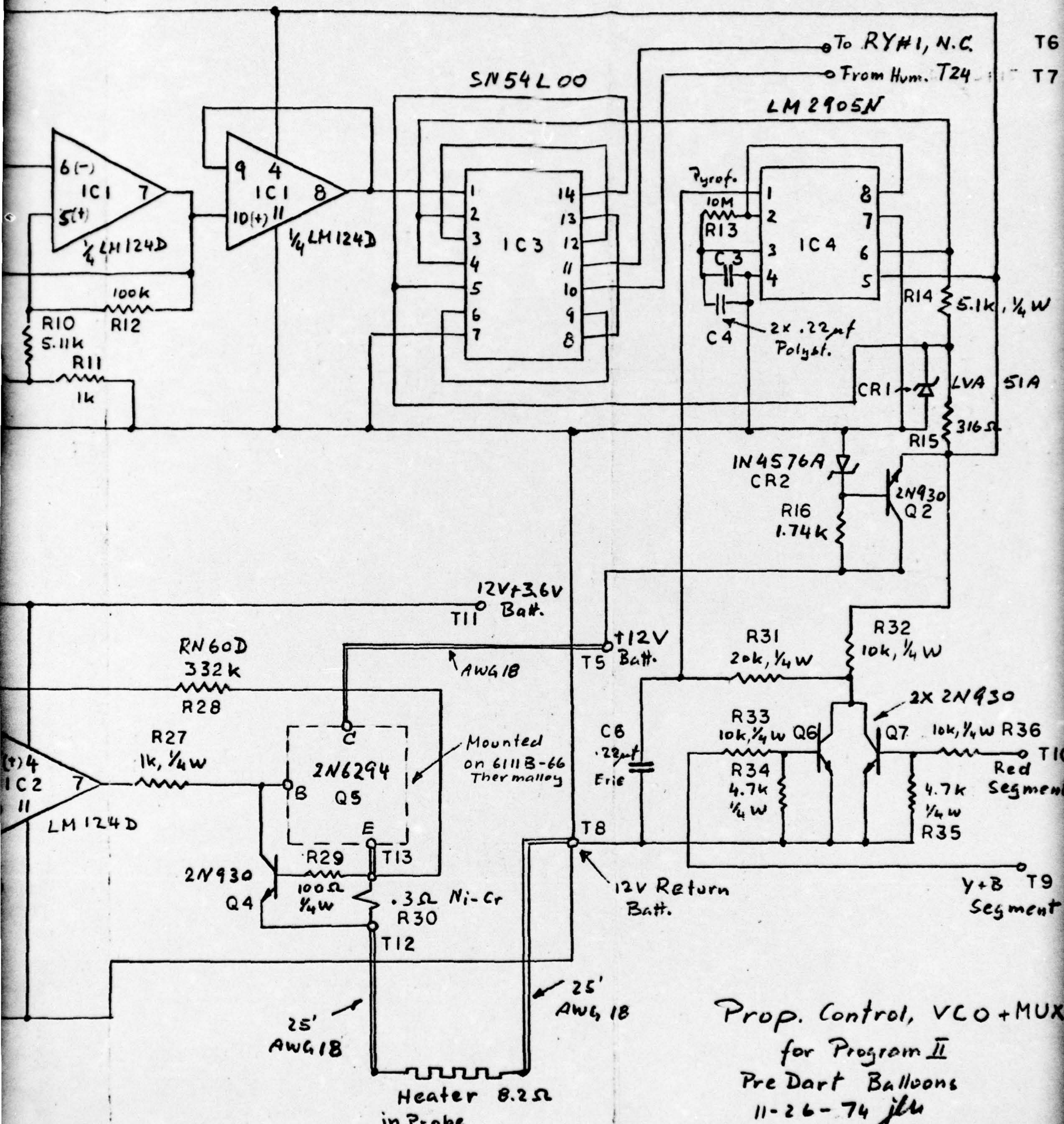
Wiring Diagram
Program II, Dual Sensor



BALLOON CUT-DOWN
& VALVE CKT.



All Res. RN55D, except where noted



Prop. Control, VCO + MUX
for Program II
Pre Dart Balloons
11-26-74 jlh

Rev. 1: Chg. Thermistor T2 to grd., remove
R1 = 1k. . Freq. out will be inversely
prop. to Temp. 8-13-75