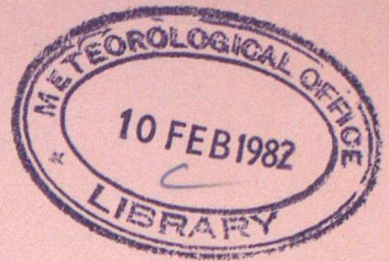


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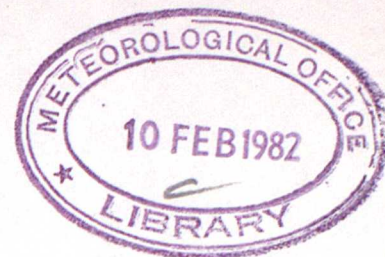
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# MET.O.15 INTERNAL REPORT

No. 15

EVALUATION OF THE CARBON HYGRISTOR AS A HUMIDITY  
ELEMENT FOR THE NAVAID DROPSONDE

by

J Gibbs, A F Lewis and P Ryder

April 1975

Cloud Physics Branch (Met.O.15)



# Evaluation of the carbon hygristor as a humidity element for the

## NAVAID dropsonde

J. Gibbs, A. F. Lewis, P. Ryder

### 1. Introduction

The Cloud Physics Branch of the Meteorological Office has, for some time, been developing a NAVAID dropsonde for mesoscale investigations of weather systems. One of the requirements of this sonde is that it should have the capability of determining the ambient atmospheric humidity. The work described in this report is part of an evaluation programme of various types of humidity element which was undertaken to fulfill this requirement. After an initial literature search and following a limited test of transducers available to us it became apparent that the carbon hygristor was at least worth a detailed study of its characteristics. Surprisingly, to our knowledge, such a study has not been made previously in this country, and until recently, (Drousaides 1973) no comprehensive evaluation has been available from the main users of the device in the United States. It is hoped that the work reported here will also be of value to other potential users with similar requirements.

The initial investigations into the manufacture and properties of carbon humidity elements were started in 1942 as a joint project between the U.S. Army Signal Corps and Eastman Kodak Laboratories. Early work was directed towards developing methods of manufacture which would yield production batches of stable reproducible elements. The carbon hygristor is currently in operational use in most U.S. radio sondes. At present there are three types commercially available, the ESSA 'fast response' type designated 'CM', the ML-476/AMT and the ML-630/AM. As a fast response to humidity changes is desirable for our application the 'CM' type has been used throughout the work reported here.

The carbon hygristor is an adsorption type element and like most of this type the physical processes governing the interaction between the adsorbing medium and water vapour are imperfectly understood. Nevertheless the electrical resistance of the device varies with humidity in what is stated to be a stable and reproducible manner. The element as produced for radio-sonde use is  $2\frac{1}{2}$  in. long,  $1\frac{1}{16}$  in. wide and 0.040 in. thick, and consists of a flat acrylic strip whose longer edges are metalised. This strip is covered with a gelatinous cellulose coating which contains a finely divided suspension of carbon particles. Adsorption of water vapour causes the cellulose to swell resulting in an increase in the average distance between carbon particles in suspension which in turn results in an increase in electrical resistance with increasing humidity, desorption of water vapour from the cellulose gives a corresponding decrease in electrical resistance.



Our investigations have been directed towards an evaluation of element characteristics such as the sensitivity of the element to humidity and temperature changes, the magnitude of the element hysteresis and its dynamic response. A small sample of elements (7) has been used in a series of laboratory calibrations to determine how the device performance compares with the manufacturers specification and these results have been supplemented by a number of field tests in which carbon hygristors have been flown on specially prepared radio sondes. Our results and those of earlier workers are described in the following sections.

## 2. Element transfer characteristics

As has been discussed previously the resistance of the carbon humidity element increases with increasing relative humidity. The manufacturer of the element has derived empirical relationships (VIZ Tech Pub 730507) which describe the variation of resistance with relative humidity at 25°C and the corrections to be applied for use at other temperatures. They suggest that the sensor will satisfactorily obey these relationships provided only that the actual resistance at 33% RH and 25°C is known either from a single point calibration made just before use or from data supplied by the manufacturer for a particular element. This resistance,  $R_L$ , is then used in :

$$\log_{10} (R) - \log_{10} (R_L) = A + B (110 - RH_{25}) - C \log_{10} (110 - RH_{25}) \quad (1)$$

where R is the sensor resistance.

$R_L$  is the 'lock in' resistance at 33% RH and 25°C.

$RH_{25}$  is the relative humidity expressed as a percentage at which the sensor has a resistance R, assuming that the ambient temperature is 25°C.

$$A = 6.0556, \quad B = 0.0111, \quad C = 3.663$$

The temperature correction is then obtained from

$$RH_T = RH_{25} + D (T - 25) \frac{(RH_{25} - 33)}{RH_{25}}$$

where  $RH_T$  is the relative humidity in per cent at temperature T°C

$$D = 0.25 \text{ at } RH_{25} > 33\% \text{ and } 0.09 \text{ at } RH < 33\%$$

The variation of sensor resistance for a typical lock in resistance of 10 K is shown as a function of  $RH_{25}$  in figure 1.



In practice it is neither necessary nor desirable to subject the sensor to an environment whose temperature is  $25^{\circ}\text{C}$  and relative humidity is 33% to determine the lock in resistance; equations 1 and 2 can be used to calculate  $R_L$  if  $T$ ,  $R$  and  $RH_T$  are known. Differentiating equation 1 for a given  $R$  we obtain the sensitivity of the determined relative humidity to changes in  $R_L$ , thus:

$$\frac{\delta R_L}{R_L} = -K_{RH} \delta(RH)$$

$$\text{where } K_{RH} = \left( \frac{3.663}{110 - RH} \right) - 0.0256$$

Because  $K_{RH}$  decreases with decreasing relative humidity it is desirable to determine  $R_L$  at low humidities. Thus if during the determination of lock in resistance,  $\delta(RH) \approx 1\%$  when  $RH \approx 90\%$  then  $\delta R_L \approx 0.16 R_L$ . An error of this magnitude in  $R_L$  when used where the ambient relative humidity is now 40% introduces an error  $\delta(RH)$  of  $\sim 6\%$ . However, if the lock in value is determined at  $RH \sim 40\%$  and  $\delta(RH)$  is again 1% then  $\delta R_L \approx 0.027 R_L$  and this magnitude of error in the lock in value produces an error  $\delta(RH) < 0.2\%$  when  $RH \approx 90\%$ . In practice during laboratory investigations the lock in resistance has been calculated from data obtained at  $\sim 40\%$  RH. However, in the field, data obtained in the base line calibration chamber are used where it is less easy to obtain very dry stable conditions, but, by drying out the chamber before use with a warm air blower, a relative humidity at lock in of 60% or less has been achieved.

Differentiating equation 1 for a constant  $R_L$  we find the sensitivity of the element resistance to relative humidity changes, thus:

$$\frac{\delta R}{R} = K_{RH} \delta(RH)$$

again there is a greater fractional change in element resistance at high relative humidities than at low values. This must be appreciated in the design of the sensor resistance measuring technique and is discussed further in section 3.1.

The temperature correction  $(RH_T - RH_{25})$  obtained from equation 2 and expressed as a function of ambient relative humidity over the temperature range  $-40^{\circ}\text{C}$  to  $+40^{\circ}\text{C}$  is shown in figure 2. As can be seen from the form of equation 2 the temperature correction becomes infinitely large as  $RH_{25}$  approaches zero. We have therefore chosen to impose a constraint that no correction shall be applied which is greater than  $0.25 RH_{25}$ . Thus all data from areas A and B are excluded from consideration as it is considered to be more desirable to exclude doubtful data than to apply large corrections. There is a second constraint, which in practice



we have not needed to invoke, such that no correction shall be applied which gives corrected values of relative humidity greater than 100%. This includes all corrections contained in area C. It should be remembered that the relative humidity used in this work is defined to the saturation as the percentage ratio of the actual vapour pressure with respect to water and therefore since homogenous ice nucleation occurs at about  $-40^{\circ}\text{C}$ , a relative humidity greater than  $\sim 67\%$  at this temperature implies supersaturation with respect to the local conditions.

### 3. Description of the laboratory apparatus and measurements

#### 3.1 Experimental method

In order to establish the effectiveness of the carbon hygistor as a relative humidity element it was necessary to perform experiments in which close control of the temperature and relative humidity of the air flowing past the hygistor could be achieved. This was accomplished using the Meteorological Office two pressure humidity generator (see figure 3, and Folland and Sparks, internal Meteorological Office report).

In this system, ambient air was pumped by a compressor through a silica gel dryer into a pressure chamber which was filled with distilled water. The saturated air then passed into a condenser and heat exchanger which was immersed in an oil bath. Saturated air from this chamber was then subjected to an isothermal expansion through the throttle valve, A. If  $p_2$  is the air pressure after the isothermal expansion and  $p_1$  is the pressure of the saturated air then :

$$\frac{p_2}{p_1} = \frac{e_2}{e_s}$$

where  $e_s$  is the saturation vapour pressure with respect to water at  $T^{\circ}\text{C}$  and  $e_2$  is the vapour pressure at  $p_2$  and  $T^{\circ}\text{C}$ . Thus,  $\text{RH} = \frac{e_2}{e_s} \times 100 = \frac{p_2}{p_1} \times 100$ , and

control of the pressure difference across the throttle valve controlled the relative humidity of the air on the low pressure side,  $p_1$  and  $p_2$  were measured by an Electro-Mechanisms pressure transducer (type FVR). Finally this air flowed through the specimen chamber containing the hygistor, whilst a fraction was bled off to pass through a dew point hygrometer to provide an additional humidity measurement. Temperature control was achieved by immersing the apparatus after the saturator in an oil bath contained in a refrigerator. This allowed control over the range  $-40^{\circ}\text{C}$  to room temperature ( $\sim 25^{\circ}\text{C}$ ). The bath temperature was measured with a secondary standard four-terminal platinum resistance thermometer. The temperature of the air flowing through the specimen chamber was verified to be the



same as that of the bath by means of a suitably mounted thermistor.

As discussed in section 2 the dynamic range of the sensor extends from 6 K $\Omega$  to 3 M $\Omega$  and is very non-linear. To limit this range and improve the linearity the hygistor was shunted by a 1.2 M $\Omega$  resistor and a 47 K $\Omega$  resistor was connected in series with their parallel combination. An AF oscillator then produced a frequency which was inversely proportional to the effective resistance of the combination, in the range 200 to 3,000 Hz. This was measured on an Advance TC/9A frequency meter.

In order to calibrate a hygistor, it was mounted in spring clips in the specimen chamber with its long axis parallel to the air flow (see figure 4). The chamber was designed to give a maximum measureable airflow of about 600 ft/min. The throttle valve was then adjusted to give a large pressure drop between the specimen chamber and the saturator and thus a low relative humidity. In practice a minimum value of just under 30% RH was achievable. From this starting point the relative humidity was increased in steps of approximately 10% up to 98% RH. The relative humidity was then changed back to  $\sim 30\%$  in similar steps. At each step in the cycle the system was allowed to stabilise, and the AF oscillator output recorded. The relative humidity was calculated both from the pressure readings and from the measured dew point. This procedure worked very well for temperatures of 0°C and above, however, icing problems within the saturation were encountered below 0°C due to condensation from the incoming air. In particular, below -10°C, the flow of air was seriously impeded and the control and measurement of relative humidity became prohibitively difficult. In order to overcome this problem, the room temperature saturator was emptied of distilled water, but the incoming air was passed through a damp cotton plug. This was found adequate to saturate the air with respect to ice at low temperatures without depositing excessive ice within the oil bath condenser. It was found that the relative humidity calculated from the pressure data still gave reasonable agreement with the relative humidity calculated using the dew/frost point data. It is of course necessary to observe the phase of the deposit on the mirror of the dew point hygrometer and apply any necessary corrections to obtain relative humidities with respect to water for use with the hygistor data. Figure 8 (c) shows a comparison between the relative humidity calculated from the pressure data,  $RH_p$ , and the relative humidity calculated from the dew/frost point data,  $RH_{Td}$ , as a function of the mean of these two quantities  $\bar{RH}$ . As can be seen the maximum difference between these two measurements does not exceed 3% RH, and no significant change was observed in this difference above and below 0°C.



### 3.2 Stability of the hygristor lock-in value

Before proceeding to the main body of the experimental work on the carbon hygristor it was considered desirable to conduct an experiment to see if the element was stable over a long period of time compared with the estimated time of operation in a laboratory calibration. To this end a hygristor was mounted in the specimen chamber and exposed to a constant relative humidity of 90% RH at 20°C for about seven hours. Over this period of time no significant change was observed in the element output. However, it was observed that the lock-in value drifted with time over a period of days (figure 5) and  $R_L$  also varied over a wide range for different sensors. This drift of the lock-in value was not considered serious provided it was determined for each individual laboratory experiment. The gradual increase in the lock-in value is consistent with our qualitative understanding of the mechanism by which the hygristor responds to relative humidity. It has been postulated (ref:- S. L. Stine :- Carbon Humidity Elements - Manufacture performance and theory. Humidity and Moisture Vol.1 p 316, 1965, Reinhold Publishing Corporation) that the structure of the cellulose deteriorates as far as its water collecting properties are concerned by the gradual crystallisation of the Hydroxyethylcellulose film due to an increase in cross-linking of molecules brought about by successive expansion and contraction of the film (corresponding to wetting and drying). Observations indicate that when this type of ordered structure is achieved then the ability of the film to expand and contract is inhibited, thus resulting in an overall loss of sensitivity accompanied by an increase in resistance of the film at low humidities. This phenomenon is in general observed in the hygristors that have been studied and manifests itself as an increase in the lock-in value resistance .

### 3.3 Temperature Dependence of the Sensor

The effectiveness of the empirical temperature correction is shown in figure 6 for the temperature range 0°C to 20°C. To assess the validity of this correction the relative humidity in the specimen chamber was held constant at about 70% RH, and the temperature of the chamber was slowly increased from 0°C to 20°C. At intervals of 1°C over this range the resistance of the hygristor was measured. As can be seen from the figure the values of relative humidity determined using the temperature correction are within 1 per cent RH of the ambient humidity in the specimen chamber. However, the measured temperature coefficient of the hygristor was -0.23 per cent RH per deg. C. This contrasts with the manufacturers quoted temperature coefficient at this RH and temperature region which is -0.13% per °C approximately. Although the data obtained are for one element and relative humidity only this discrepancy does emphasise the caution



which should be used when applying large corrections.

The manufacturers suggested correction procedure has been used throughout the report so that errors due to departures from the empirical relationship are included in the overall accuracy figures quoted in section 3.5.

### 3.4 Hysteresis of the element.

The carbon hygristor exhibits hysteresis and a typical relative humidity cycle at 20°C is shown in figure 7. The arrows on the curve indicate the direction of the relative humidity change. All the laboratory calibration measurements were started at low humidities somewhat less than 30 per cent. Figure 8 shows a plot of the average hysteresis as a function of relative humidity for all laboratory data. As can be seen the hysteresis is a maximum of just under 4 % RH at about 60% RH, gradually approaching zero towards 100 % RH. The general behaviour of the hysteresis is consistent with the explanation of this phenomenon given by Stine in Humidity and Moisture, Vol. 1. where the hysteresis is believed to be due to a surface effect of the cellulose film. When the ambient humidity is decreased from an initially high value the water release from the film is largely from the surface. This relatively rapid decrease of water molecules at the surface compared with water contained deep within the film results in a contraction of the surface which traps the water molecules absorbed in the body of the film and inhibits their release. Thus we would expect the resistance of the film to be greater on a decreasing humidity curve than on the increasing curve and correspondingly the element will indicate a higher relative humidity on the decreasing curve. It was observed that the sensor hysteresis was reduced to 2/3 its previous value if a second humidity cycle was generated shortly after the first.

According to Broussides (1973) current specifications allow for a hysteresis error of 4% RH above 33% and 5% RH at humidities between 10 and 33%.

### 3.5 Accuracy of the carbon hygristor empirical calibration

During the laboratory investigations described in section 3 three estimates of relative humidity were obtained; namely from the carbon hygristor, the dew point hygrometer and via the pressure measurements. In figure 8(a) RH is obtained from the carbon hygristor on the increasing humidity part of the cycle only (to remove hysteresis effects),  $RH_p$  from the pressure transducer data and  $RH_{T_D}$  from the dew point hygrometer and  $\overline{RH}$  is the mean of  $RH_p$  and  $RH_{T_D}$ . The mean difference between measurements taken in pairs is shown and the RMS difference about the mean is indicated by the length of the error bars.



As can be seen from figure 8(c) there is a discrepancy between the pressure and dewpoint estimates of relative humidity such that above 40% RH the former data indicate a greater humidity than the latter while the reverse is true below 40%. The maximum difference between estimates is  $\sim 3\%$ .

In figures 8(a) and 8(b) although differences between  $RH_T$  and  $RH_p$  are slightly less than between  $RH_T$  and  $RH_{TD}$ , suggesting that  $RH_{TD}$  may contain the major error the data do not allow any firm conclusions to be made. We have therefore assumed that  $\overline{RH}$  is the best estimate of relative humidity for comparison with the carbon hygristor data.

The general conclusions which can in fact be inferred from any of figures 8(a) and (b) are that the carbon hygristor appears to overestimate relative humidity at low humidities but to underestimate at humidities above about 95% RH. There is also a tendency for the RMS error to increase at low humidities.

Figure 9 shows the mean difference (and RMS difference about the mean) between the carbon hygristor and  $\overline{RH}$ . All data have been used therefore the effects of hysteresis errors and temperature compensation are included. No significant differences were observed between the forms of the error variation over the temperature range  $+20^\circ\text{C}$  to  $-30^\circ\text{C}$ .

Comparison between figures 8(a) and (b) and 9, suggest that apart from the region above 95% RH the elements tested tended to overestimate the humidity. This was largely, but not entirely, due to hysteresis effects. RMS errors about the mean difference between  $RH_{viz}$  and  $\overline{RH}$  do not exceed 5% and although not explicitly demonstrated in figure 9 the maximum overall RMS difference is  $\sim 6\%$  with an average value of 4.5%. The manufacturer's tolerance is stated to be  $\pm 3\%$  RH at  $25^\circ\text{C}$ ,  $\pm 5\%$  RH,  $< 25^\circ\text{C}$  exclusive of hysteresis effects.

### 3.6 Response time of the element

Marchgraber and Grote (1965) and Brousaides (1973) have investigated the response of the carbon hygristor type ML-476 to step changes in humidity, and the former workers draw attention to the fact that the response is not exponential but can be simulated by the sum of two exponential functions with different time constants. Brousaides has summarised his results and those of Marchgraber and Grote by evaluating the time taken for the element to respond to 90% of the impressed step function; we followed this example. He found that this response time increases for decreasing temperature and decreases with increasing flow rate. He also demonstrated that the response time was longer for decreasing than for increasing relative



humidity changes. The carbon humidity element reported in this work was the so called 'fast response' type so we have attempted to determine response times for this element. The two pressure humidity generator has the facility to introduce a rapid change of RH in the specimen chamber which approximates to a step function. Unfortunately it was not possible with the present design to achieve precise control of the flow rate after the step was generated. For this reason the data obtained consist of response times at various flow rates. We were also unable to accurately specify short time constants because of the method of recording. The results are presented in figure 10 together with those of Brousaides etc. for the ML 476 element. Our results are in reasonable agreement with those of the earlier workers bearing in mind our lower average flow rates, without being as comprehensive. The error bars arise from our uncertainty in defining a 90% level where the observed rate of change of humidity was very low. We did, however, observe significantly shorter response times for the flow rate achieved at low temperatures and decreasing humidity than did Marchgraber and Grote. This may be due to our use of the fast response hygrometer.

#### 4. Sonde evaluation

In an attempt to test the carbon humidity element in the atmosphere a radio-sonde was constructed. This incorporated the latest humidity duct from a U.S. National Weather Service sonde but was compatible with Meteorological Office sonde receiving system. The form of construction is shown in figure 11 and a block diagram of the electronics is shown in figure 12. Two versions of this sonde designated U and UT were used. In the first of these only the carbon humidity element was incorporated, so that continuous relative humidity data were transmitted. The temperature AF oscillator and switch shown in figure 12 were therefore not included in the electronics package. In the second a bead thermistor, Yellow Springs Industries, Type 44105 was mounted in the humidity duct behind the carbon hygistor. The hygistor was connected in an AF oscillator as described in section 3.1 and when used, the clock and switch connected the humidity and temperature oscillators successively to the 27 MHz transmitter. Humidity data were obtained for 8 seconds of the 10 second commutation cycle in this case.

The resistance - frequency transfer characteristics were obtained by pre-flight calibration using a series of standard resistors connected in place of the carbon hygistor and thermistor (where appropriate) and the lock in resistance was determined from a base line calibration immediately before launch. The sensitivity of the AF oscillator to temperature changes was very low except at low humidities where the maximum error was  $\sim 5\%$  RH.



The sonde data were recorded on the Met.0.15 data logger and the pre-flight calibration data used together with known characteristics of the thermistor and equations 1 and 2 of section 2 to determine temperature and relative humidity as a function of time.

#### 4.1 Ascent of 1/10/73

A 'U' type sonde was suspended approximately 20 ft beneath a Standard Met. Office Mk 2 B radio sonde which was released from the experimental site at Beaufort Park at 1400Z on 1/10/73. The surface relative humidity and temperature from the nearby screen were 54% and 13.1°C respectively. The RH determined from the U sonde and the RH and temperature derived from the Mk 2B radio sonde are shown in figure 13. The sonde was observed to enter thin stratocumulus cloud approximately 4 mins after release. The indicated Mk 2B relative humidities at release and during cloud penetration at least, was rather low and we believe that this transducer under-estimated humidity throughout the flight. Nevertheless despite the much greater amplitude of changes as measured by the U sonde there is excellent time agreement between the fluctuations observed. Clearly the carbon hygistor had a much shorter response time than the Mk 2B 'goldbeaters skin' element. It is not known whether the constant humidity measured by U sonde from minute 5 to 11 is real or whether the element became insensitive at a relative humidity of 22%; of the latter, this effect was not observed on any subsequent ascent. The data from the two sondes were plotted on the tephigram shown in figure 14.

#### 4.2 Ascent of 3/12/73

A 'U' sonde was suspended beneath a Standard Mk 2B radio sonde as on the 1/10/73. Unfortunately data from the latter were not received until minute 4 and were lost shortly after minute 20. The time variation of relative humidity and temperature calculated from both sets of sonde data are shown in figure 15. There is very good agreement between the form of the relative humidity variations obtained from the two sondes, although again the response of the Mk 2B element is much slower. The very sharp humidity gradients observed at about minute 6 were recorded by both transducers but unfortunately the Mk 2B transmitted pressure and temperature data during the minimum detected by the carbon hygistor. The gaps in the data from the latter occur when the temperature corrections exceeded the limits discussed in section 2. The sonde data are also plotted in the tephigram of figure 16.



#### 4.3 Ascent of 22/1/73

A 'U' sonde was suspended beneath a 'UT' sonde and both were launched on a single balloon from Beaufort Park as before. The day was one of heavy overcast with some light precipitation and apart from the desire to observe the extent of the agreement between the two carbon hygriators, their performance in a high liquid water content environment was sought. On both counts the elements gave excellent results as can be seen from figure 17, where the relative humidity variations through the ascent are shown. The maximum difference between elements away from strong gradients is 3% and this occurred at temperature close to  $-30^{\circ}\text{C}$ . In an attempt to investigate the pronounced hydrolapse observed around minute 9, this section of the flight is shown on an expanded time scale in figure 18. Because of the distance between the sondes when suspended beneath the balloon, a two second time difference between the traces is expected and observed. The gaps in the UT data are because of temperature transmissions at these times. The tephigram obtained from the data is shown in figure 19. The obviously real structure observed at temperatures as low as  $-35^{\circ}\text{C}$  is worthy of note and the extremely good agreement (  $0.8^{\circ}\text{C}$  in dew point) is encouraging.

#### 5. The use of the carbon hygriator as a meteorological transducer

We have observed that the lock in resistance of the carbon hygriator is not conserved over a time scale of days so the device does not show promise as a humidity transducer in a long term data gathering system. However, as a short term sampling transducer it does exhibit several desirable features, e.g. low cost, freely available, simple to prepare and use.

The question as to the suitability of a given transducer must depend upon the purpose for which the results are required. In our application the humidity data will be used to delineate cloud and air mass boundaries from a package falling at about 1800 ft/min. We have observed that the device (in the latest N W S duct at least) responds well after exposure to a high liquid water content environment (section 4.3). Stine (1965) has reported that the elements are highly resistant to washout. Elements immersed in water for several hours were found to respond to within 3% RH after removal of the liquid. Brousaides (1973) presents data obtained by the National Bureau of Standards and by himself which indicates that the hygriator does change calibration after spraying such that above 30% RH at least the inferred relative humidity is too low. However, he concludes 'that the data should be reasonably acceptable as long as the hygriator has not passed through heavy precipitation'.



Our data on the response time of the 'fast response' carbon hygristor suggests that at temperatures above  $-20^{\circ}\text{C}$  even if the flow over the element is only  $1/3$  of the sonde fall speed, 90% of any step change will take place within 40 seconds (i.e.  $\sim 400$  metres) as the sonde moves from a wet to dry environment. In addition a drop sonde normally experiences the major humidity gradients (i.e. those at an inversion) as a change from low to high humidity when the response time is expected to be even less than quoted above.

Quantitative estimates of relative humidity will largely be used for determination of wet bulb potential temperature for isentropic studies, the delineation of air mass boundaries and the definition of actual and potential instability. It is therefore very interesting to look at the sensitivity of wet bulb potential temperature,  $\Theta_w$ , to changes in relative humidity. In figure 20  $\partial\Theta_w/\partial(\text{RH})$  is shown as a function of air temperature for extremes of relative humidity. The variation is very insensitive to the pressure at which T and RH are measured. The R.M.S. error in RH obtained in our laboratory calibrations was  $\sim 5\%$  so that we may expect the R.M.S. error in  $\Theta_w$  to contain a maximum contribution of  $\sim 0.5^{\circ}\text{C}$  at temperatures above  $0^{\circ}\text{C}$  and  $0.3^{\circ}\text{C}$  or less below this, from uncertainties in the relative humidity. It is expected that air temperature will be measured to at least  $\pm 0.2^{\circ}\text{C}$  so that except at very low temperatures the  $\delta(\text{RH})$  is likely to provide the major contribution to  $\delta\Theta_w$ . A typical change in  $\Theta_w$  across an air mass boundary is likely to be  $\sim 5^{\circ}\text{C}$  so that  $\delta\Theta_w < 0.5^{\circ}\text{C}$  would appear adequate for the delineation of air masses at least. Single ascents of the type described here are not sufficient to provide information on the suitability of carbon hygristors to obtain  $\Theta_w$  cross sections. Some of the fine scale features detected by the carbon hygristors may not be representative over large areas and therefore their inclusion will merely introduce sub grid scale variance for aliasing into the cross-section. However, it is very likely that greater accuracy of large scale variations in  $\Theta_w$  will be provided by the carbon hygristor than by 'goldbeaters skin' for example. Potential wet bulb temperatures derived from the two transducers are compared in figures 21 and 22.



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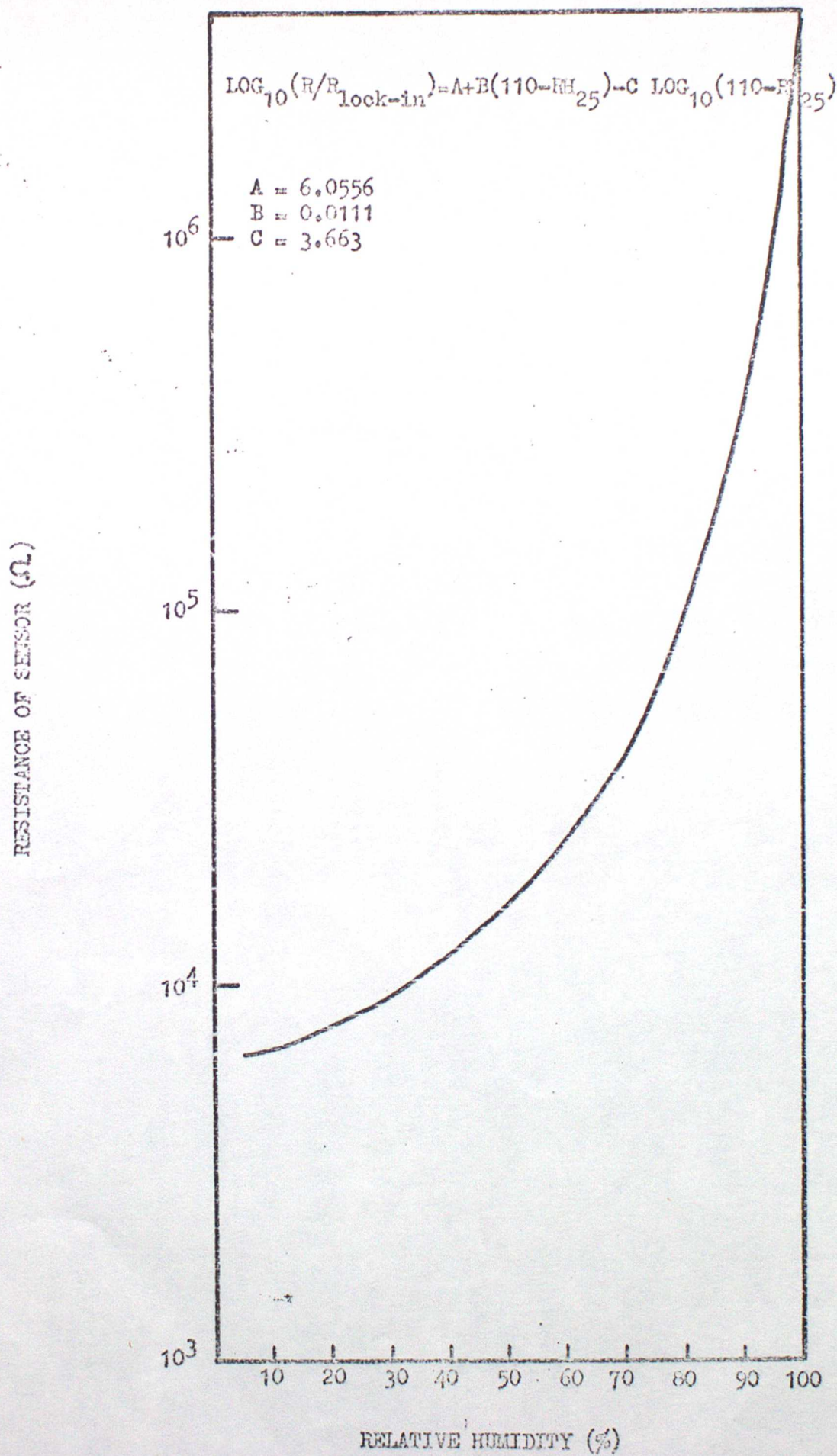
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FIG. 1 . EMPIRICAL RELATIONSHIP DEMONSTRATING THE RESISTANCE OF  
SENSOR AS A FUNCTION OF RELATIVE HUMIDITY





CORRECTION TO RH DETERMINED FROM STANDARD RELATIONSHIP  
 TO TAKE ACCOUNT OF AMBIENT TEMPERATURE ( $RH - RH_{25}$ )

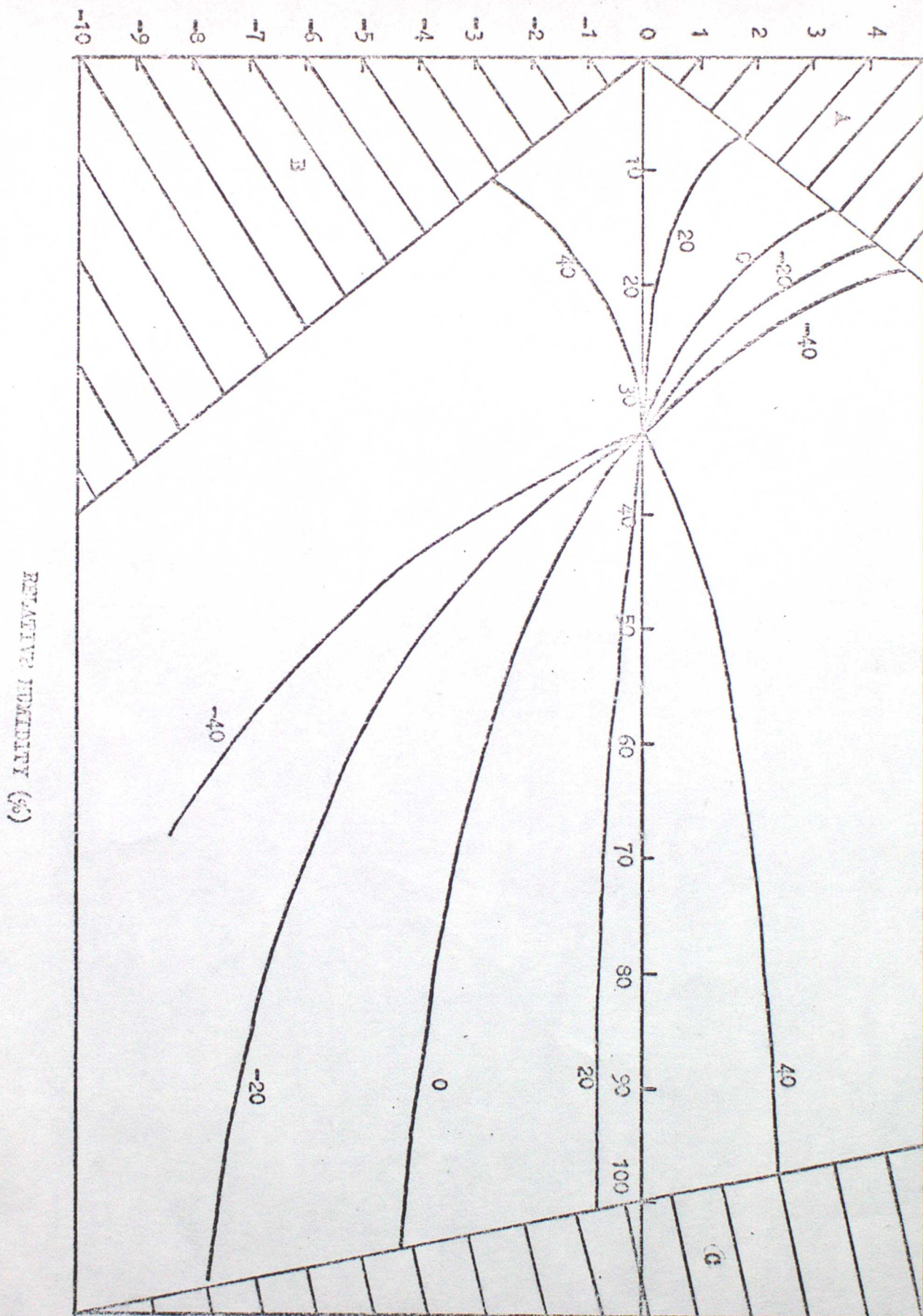


FIG. 2. DEMONSTRATION OF TEMPERATURE CORRECTIONS WHICH ARE MADE TO THE STANDARD SENSOR TRANSFER CHARACTERISTIC



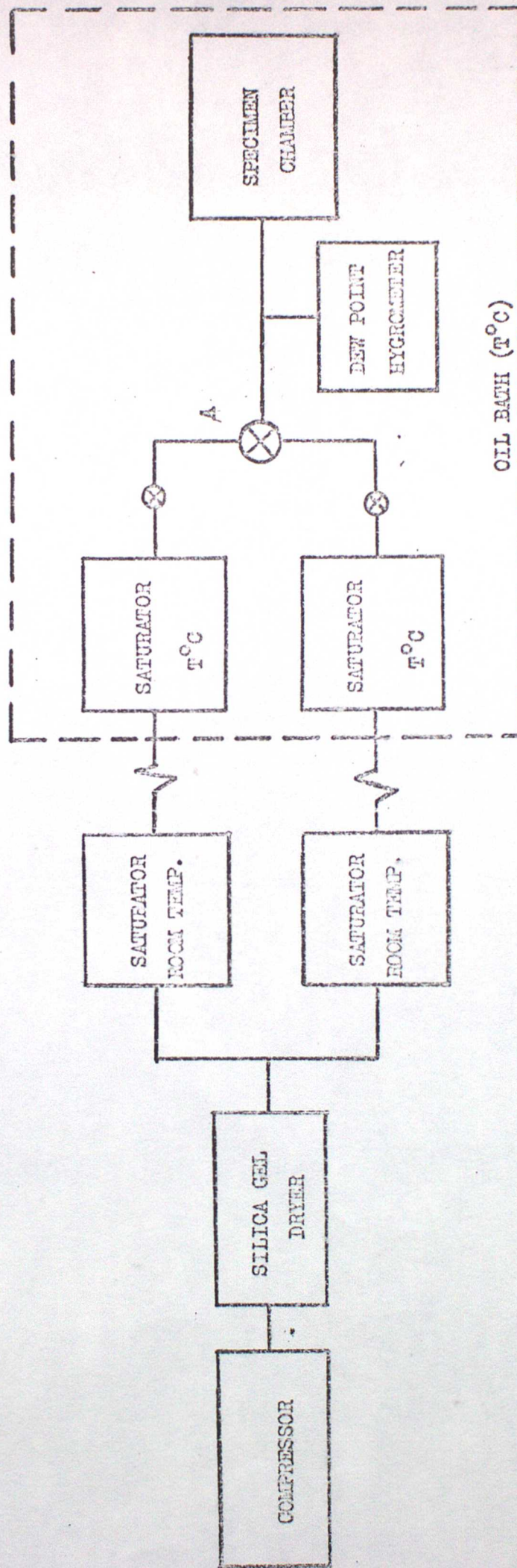


FIG. 3. SCHEMATIC DIAGRAM OF THE TWO PRESSURE HUMIDITY GENERATOR



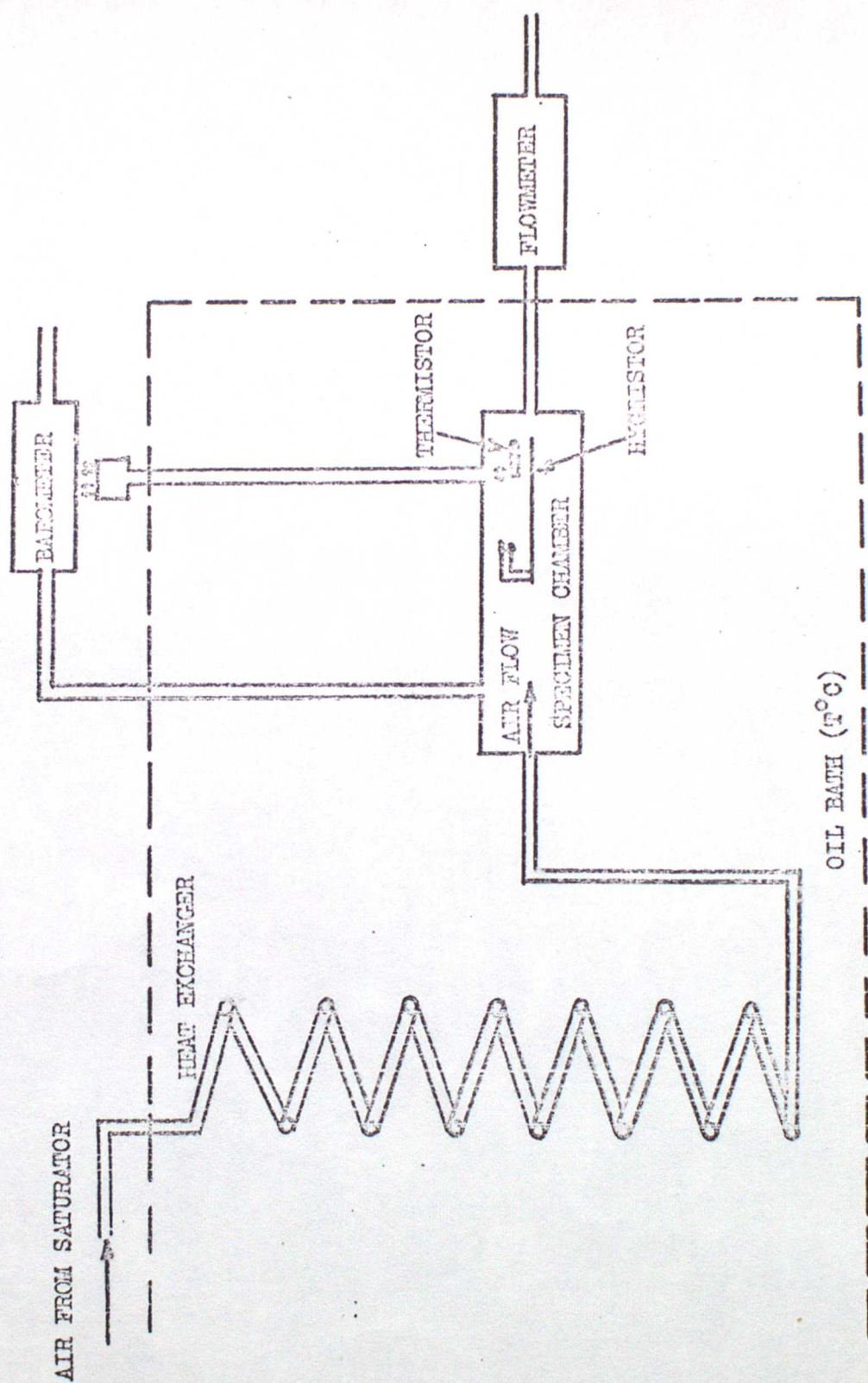


FIG.4. SCHEMATIC DIAGRAM OF THE SPECIMEN CHAMBER AND HEAT EXCHANGER



FIG.5. LOCK-IN RESISTANCE AS A FUNCTION OF TIME

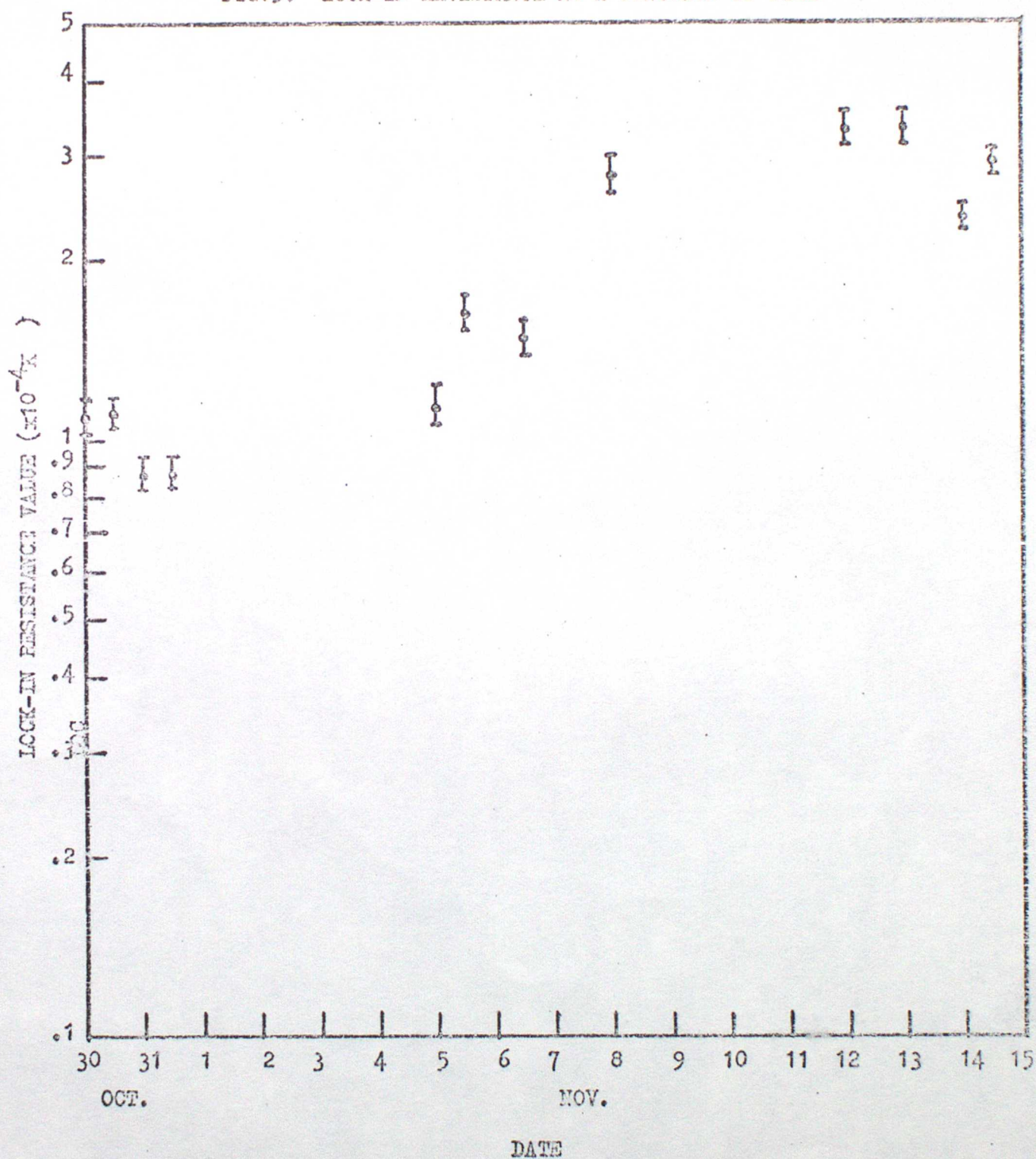




FIG. 6 . EFFECT OF TEMPERATURE COMPENSATION

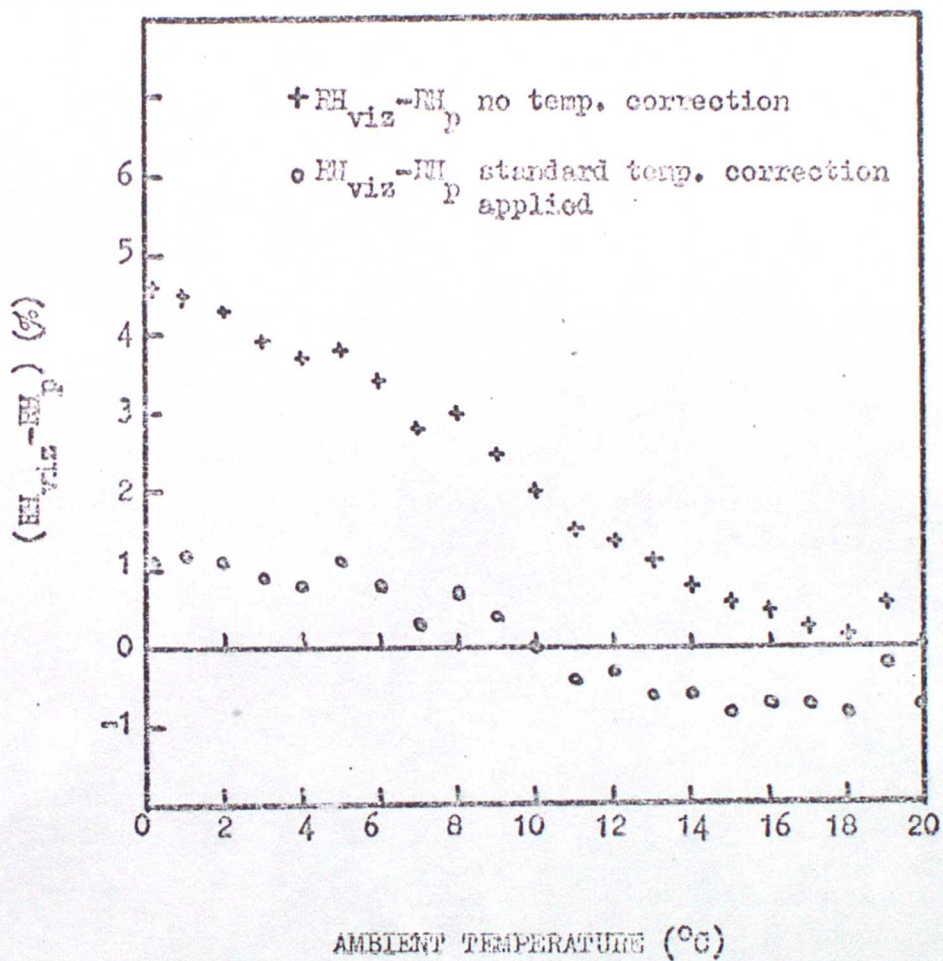




FIG. 7. A TYPICAL RELATIVE HUMIDITY CYCLE AT 20°C

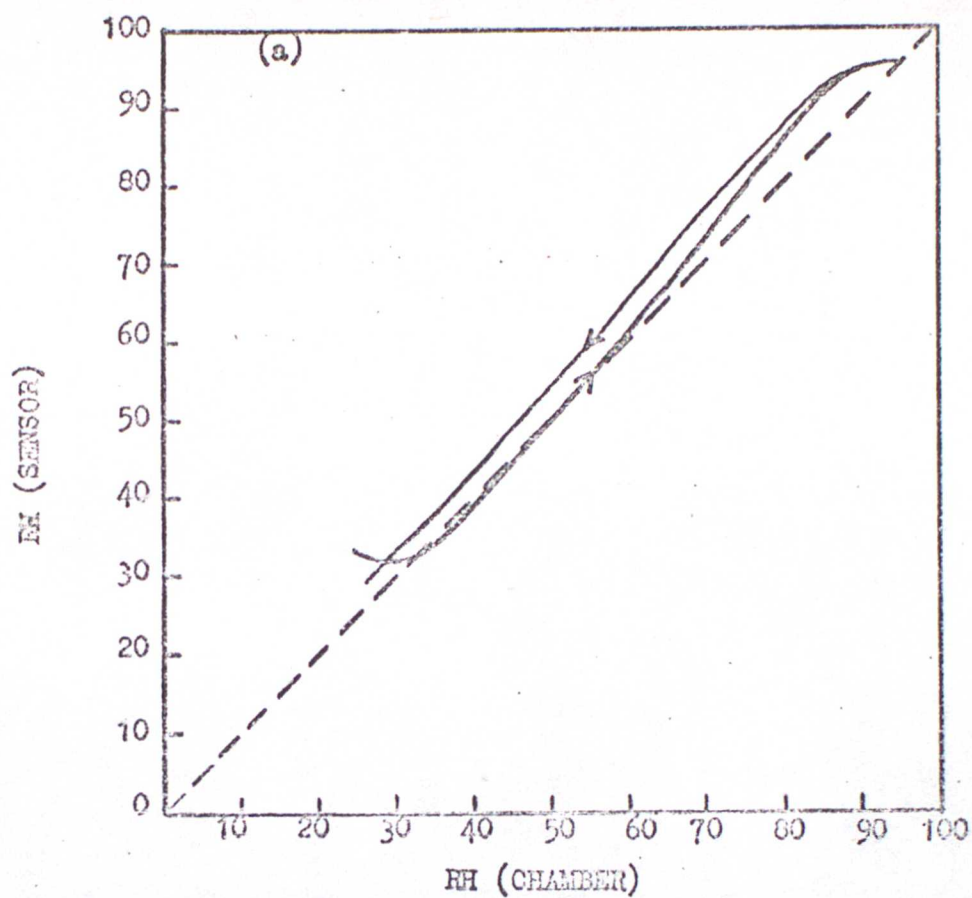


FIG. 7. HYSTERESIS AS A FUNCTION OF RELATIVE HUMIDITY

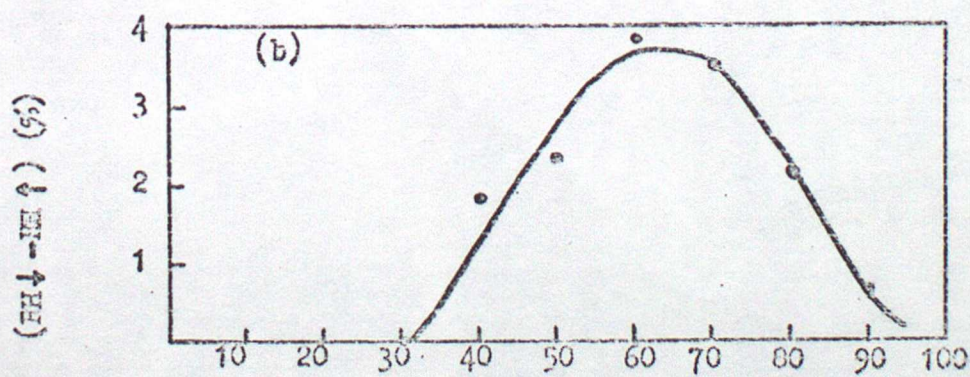




FIG. 8. MEAN ERROR IN  $(RH - RH_p)$  AS A FUNCTION OF  $RH$

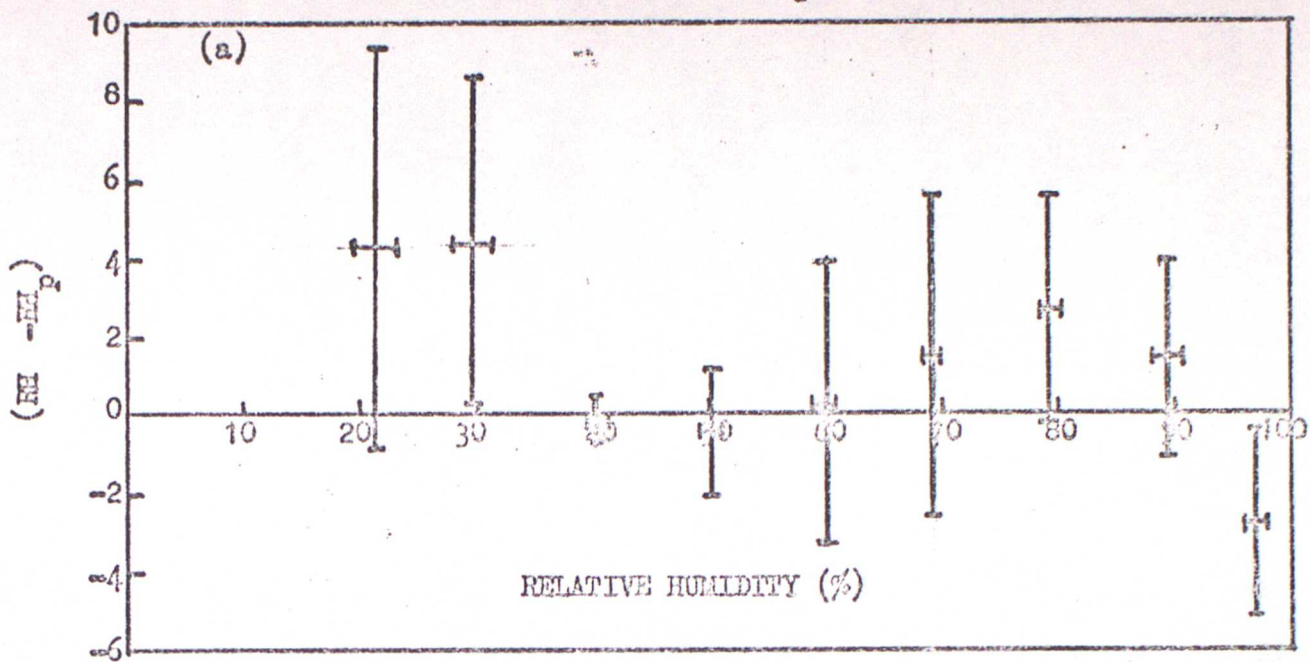


FIG. 8. MEAN ERROR IN  $(RH - RH_{TD})$  AS A FUNCTION OF  $RH$

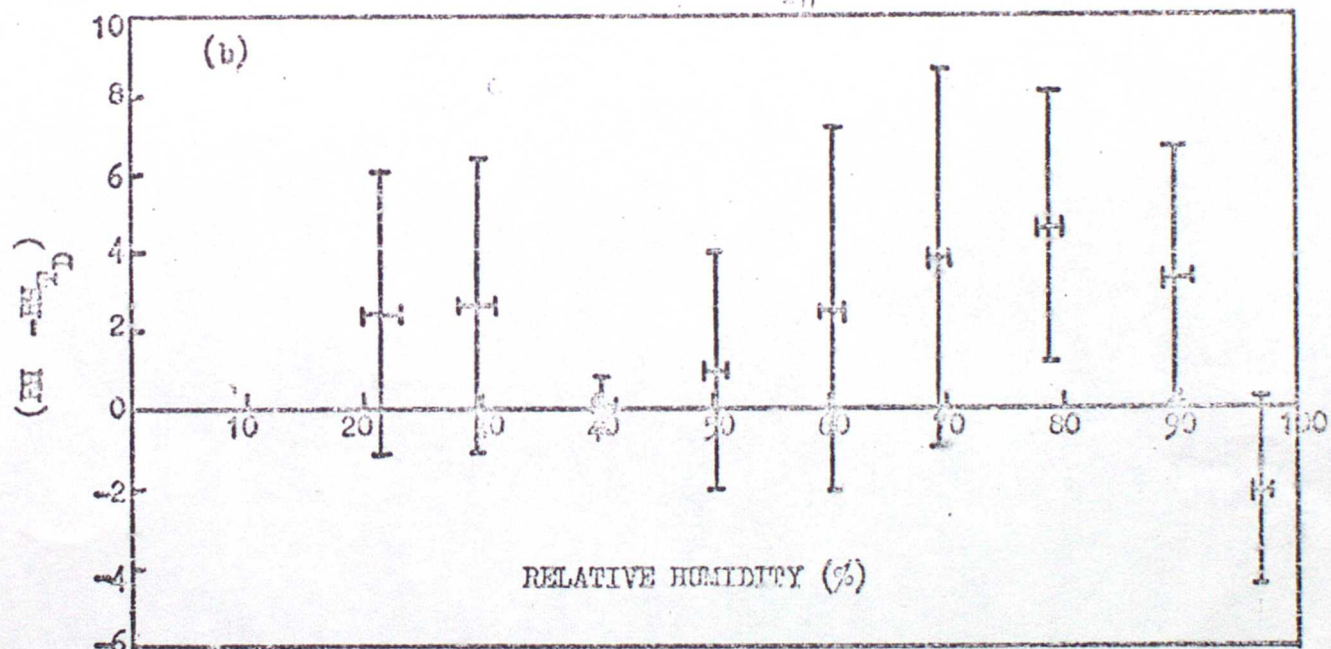


FIG. 8. MEAN ERROR IN  $(RH_p - RH_{TD})$  AS A FUNCTION OF  $RH$

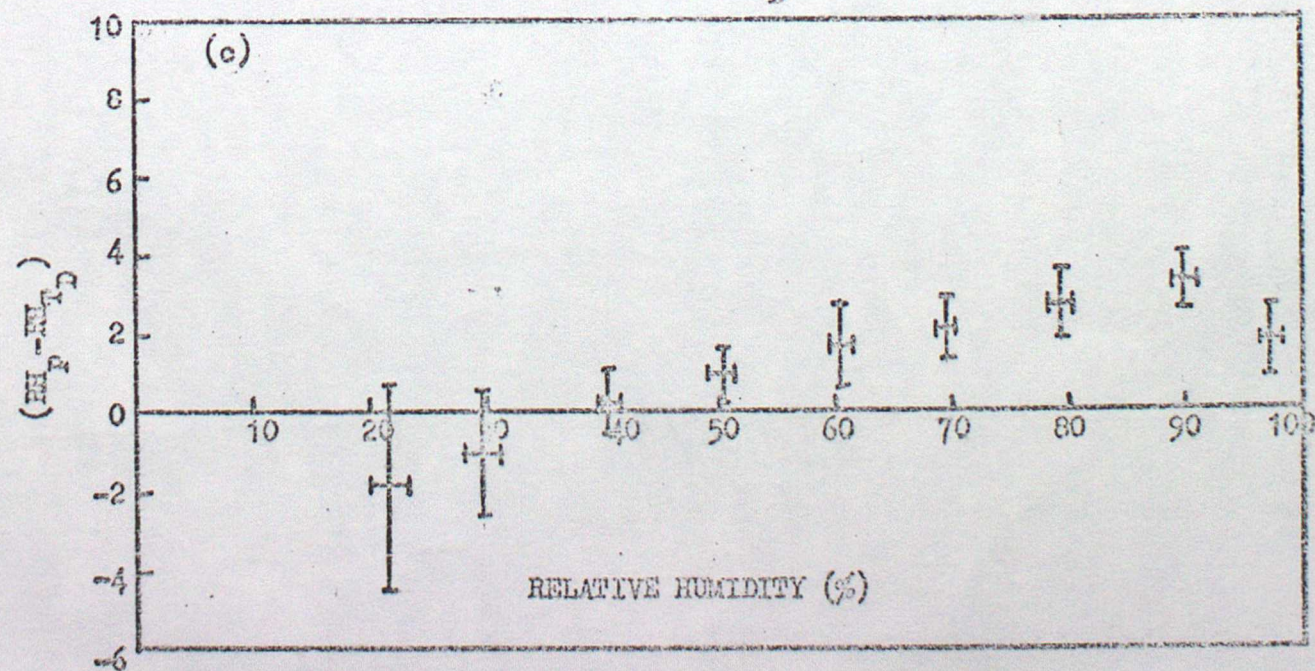




Fig. 9 . MEAN ERROR IN  $(RH_{viz} - \overline{RH})$  AS A FUNCTION OF  $\overline{RH}$

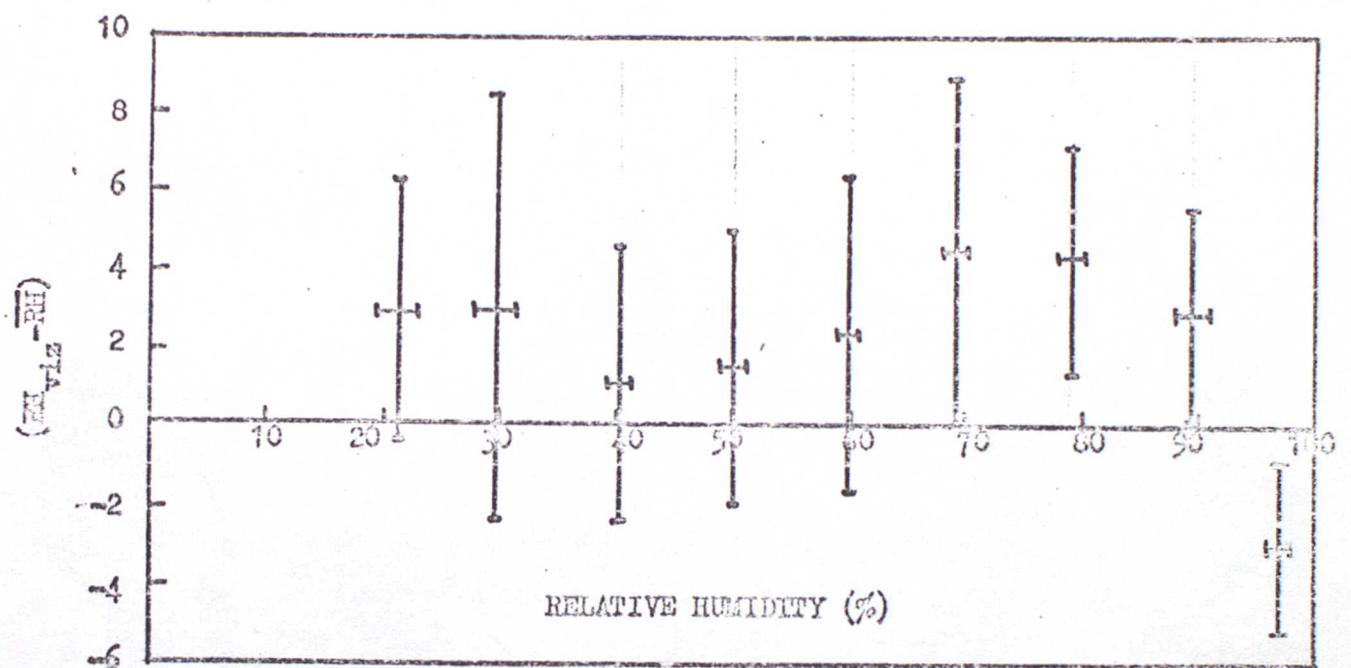




FIG.10. RESPONSE TIME AS A FUNCTION OF TEMPERATURE

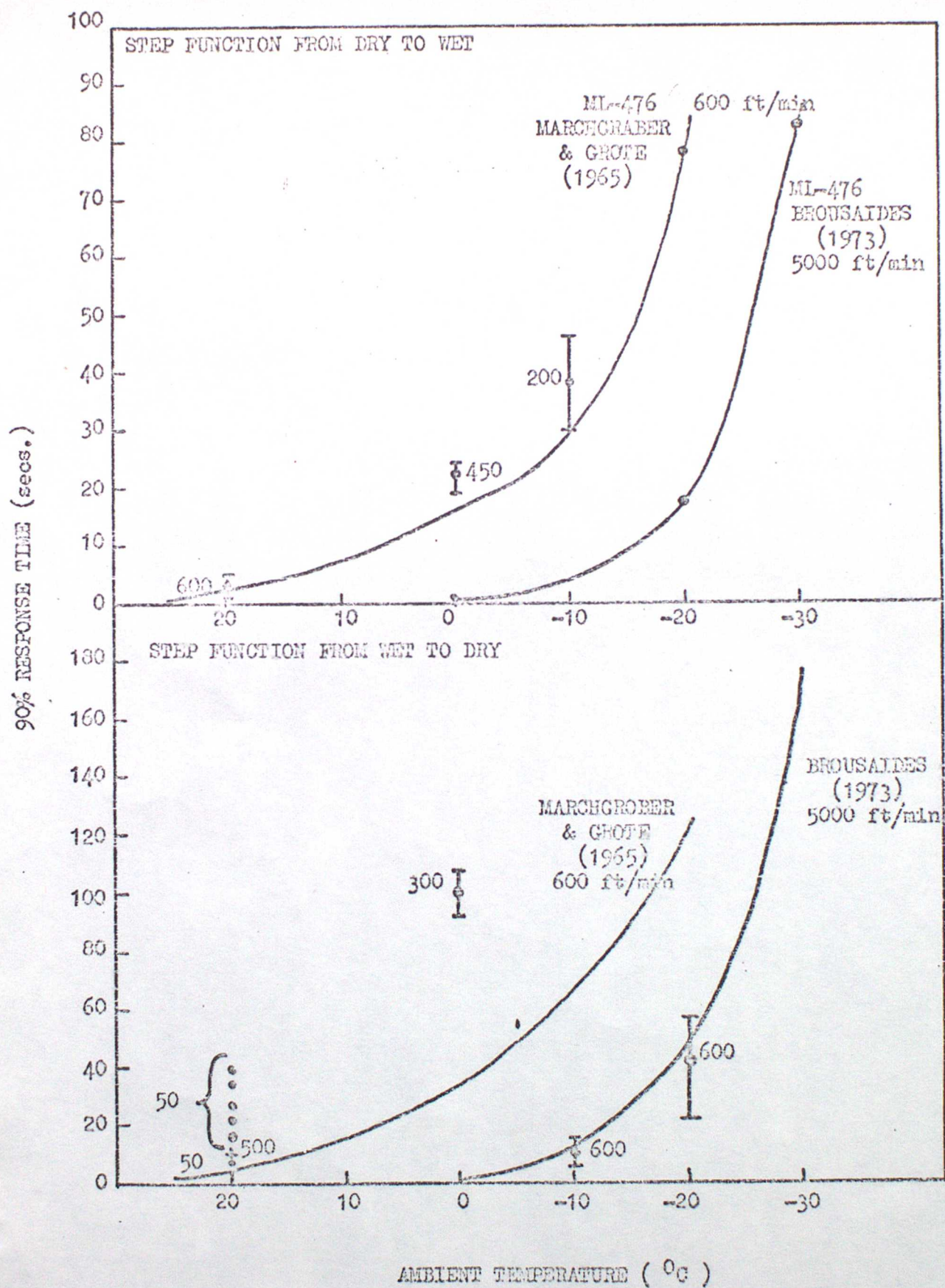
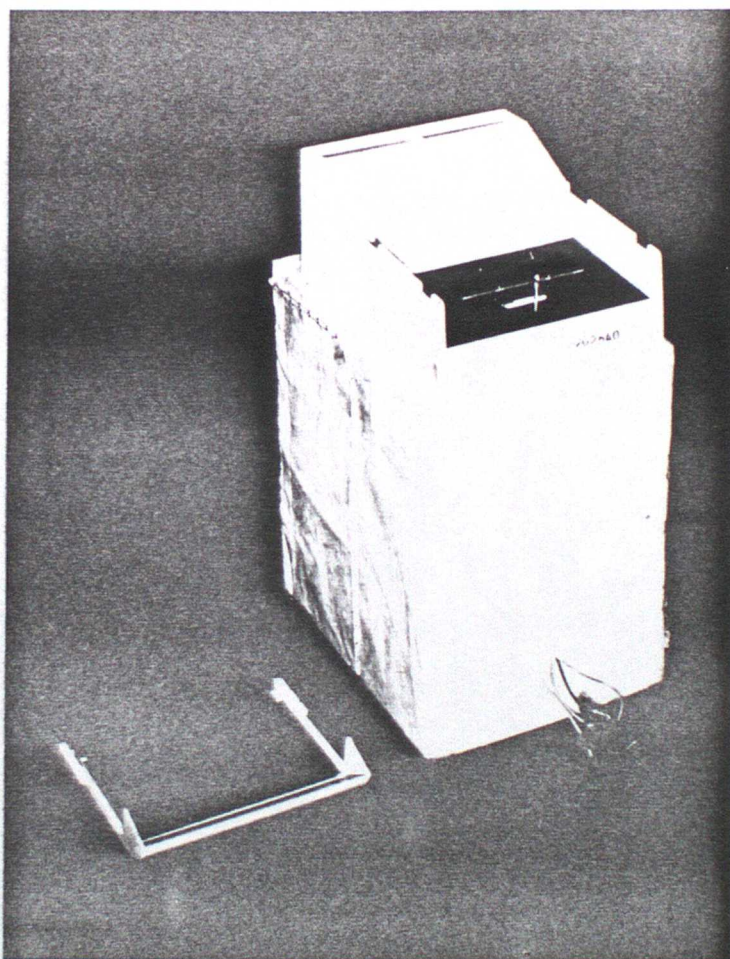




FIG. 11. FORM OF CONSTRUCTION OF EXPERIMENTAL RADIOSONDE (SHOWING THE CARBON  
HYGRISTOR 'in situ')





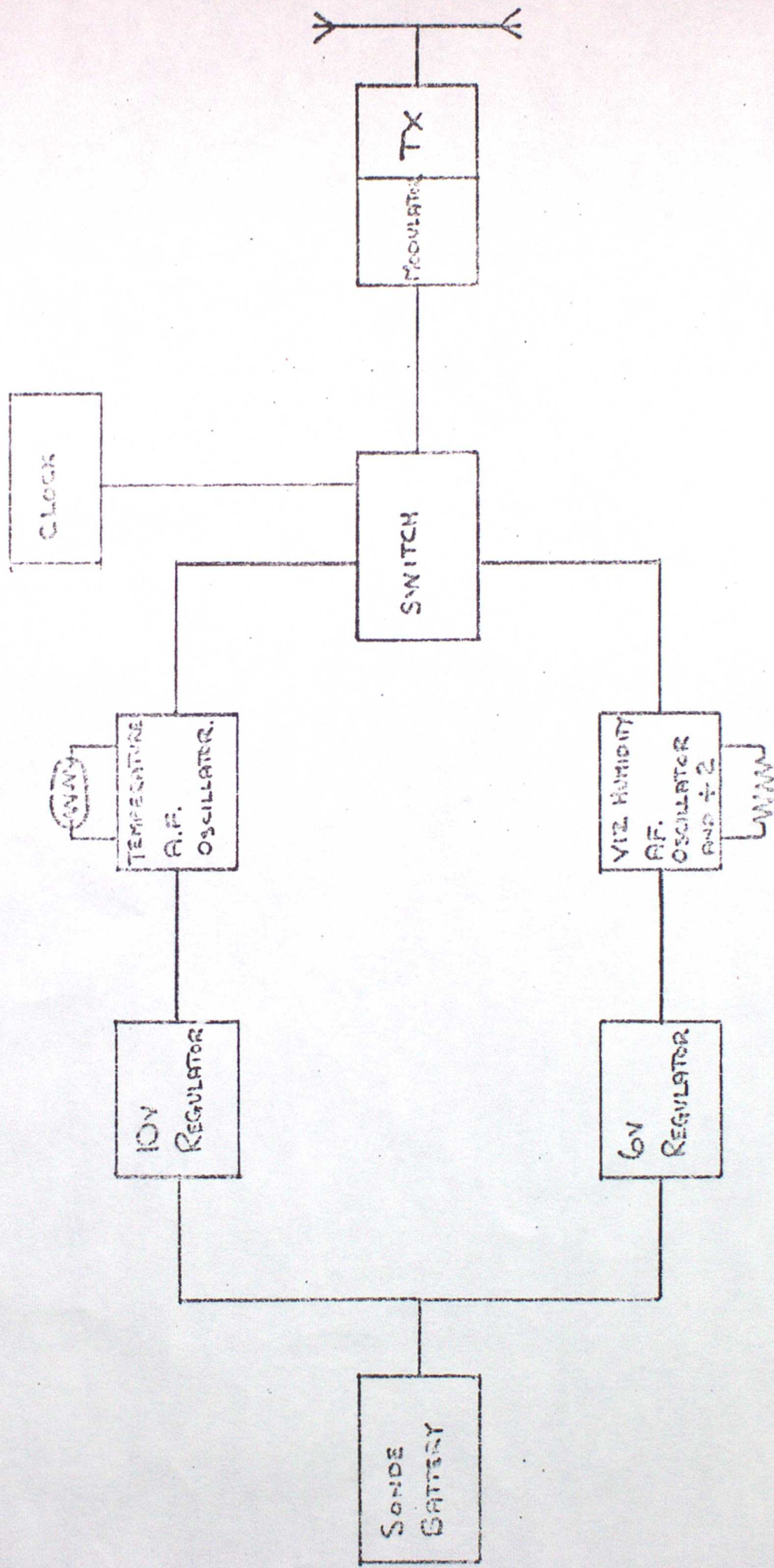


FIG. 12 BLOCK DIAGRAM OF U.T. SONDE ELECTRONICS.



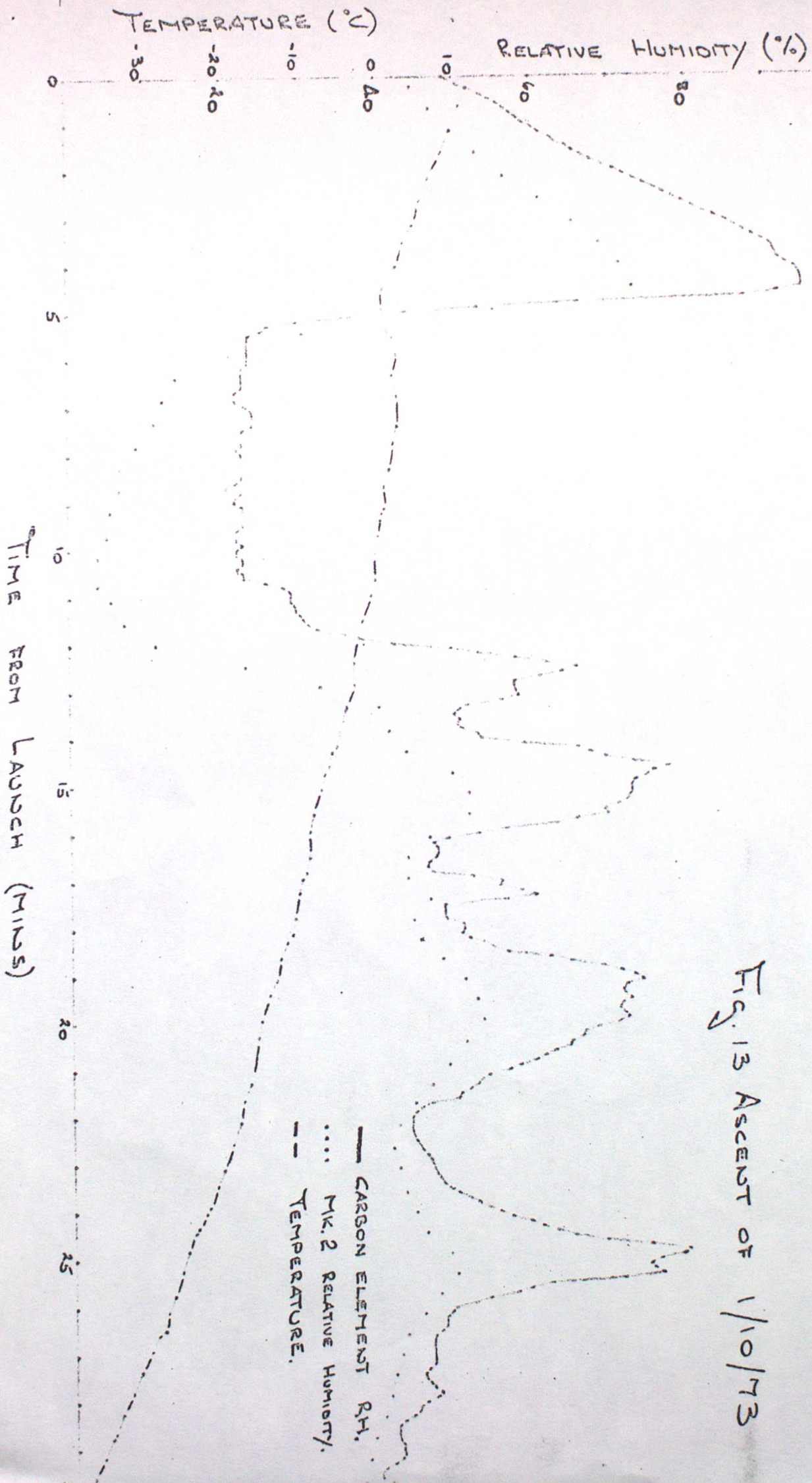
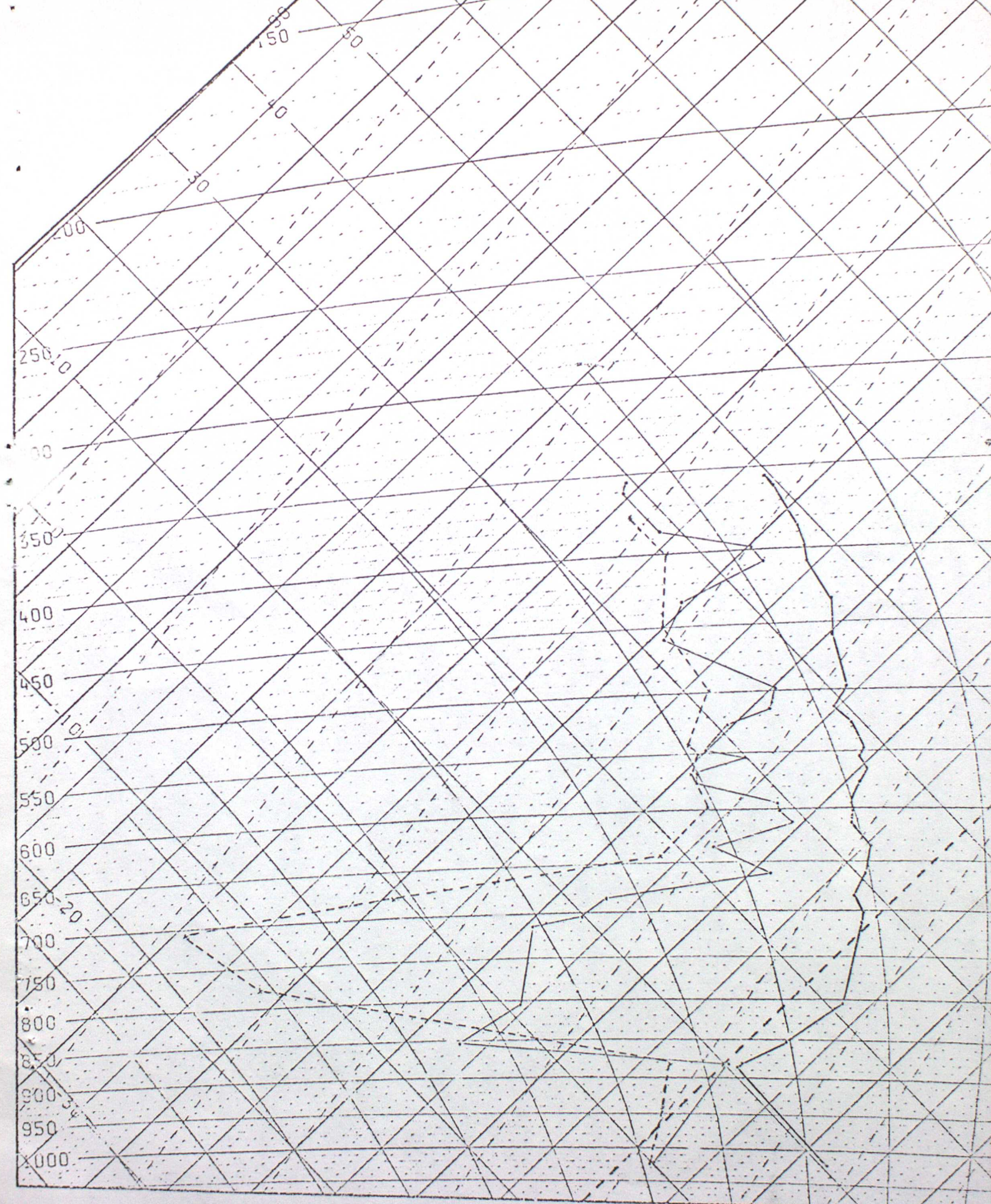
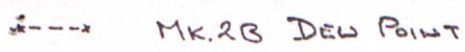
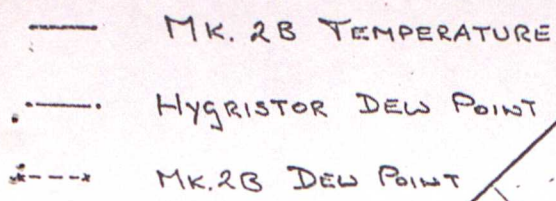


FIG. 13 ASCENT OF 1/10/73



Fig. 14 ASCENT OF 1/10/73





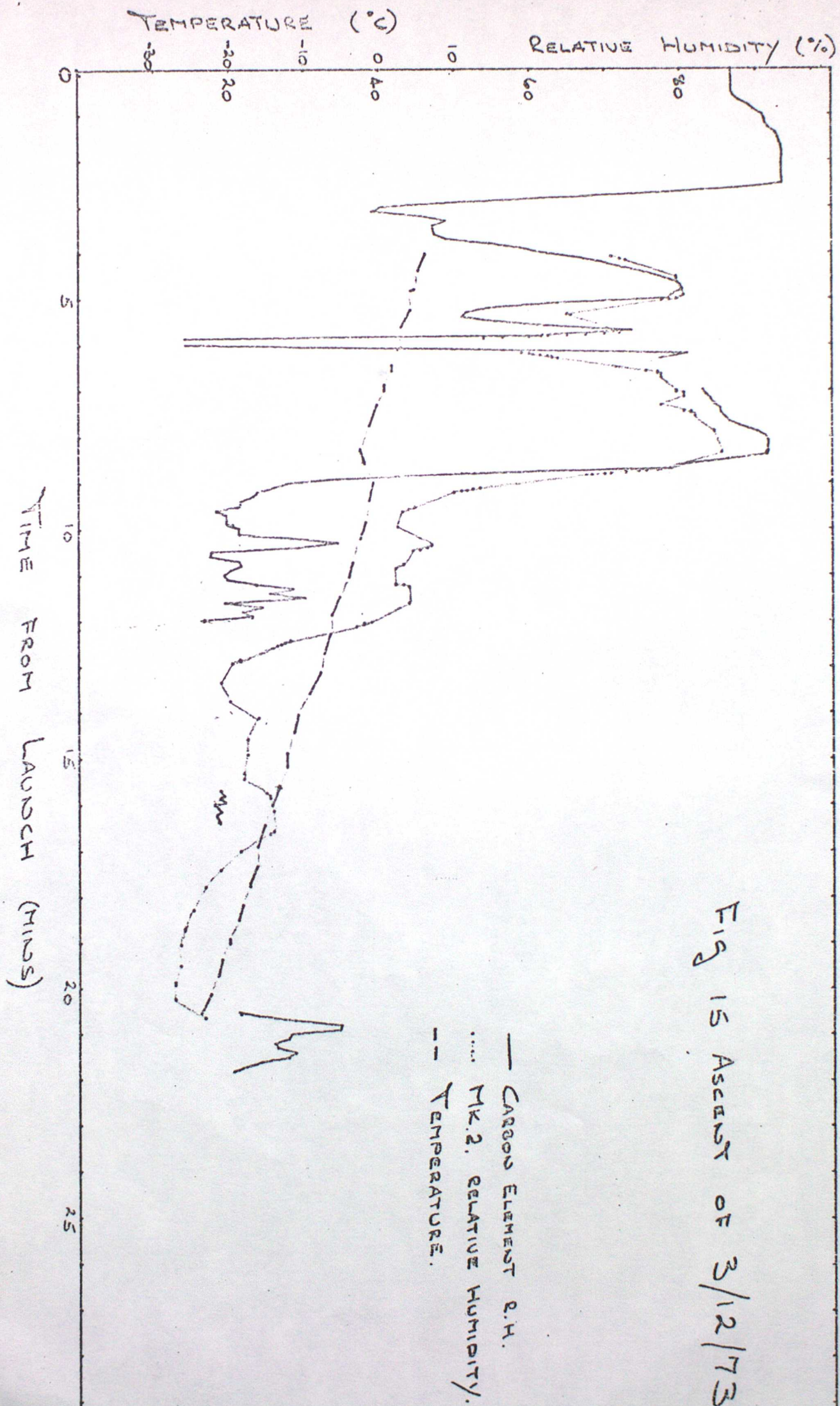




Fig 16. Ascent of 3/12/73

— MK.2B TEMPERATURE

—•— HYGRISTOR DEW POINT

..... MK.2B DEW POINT

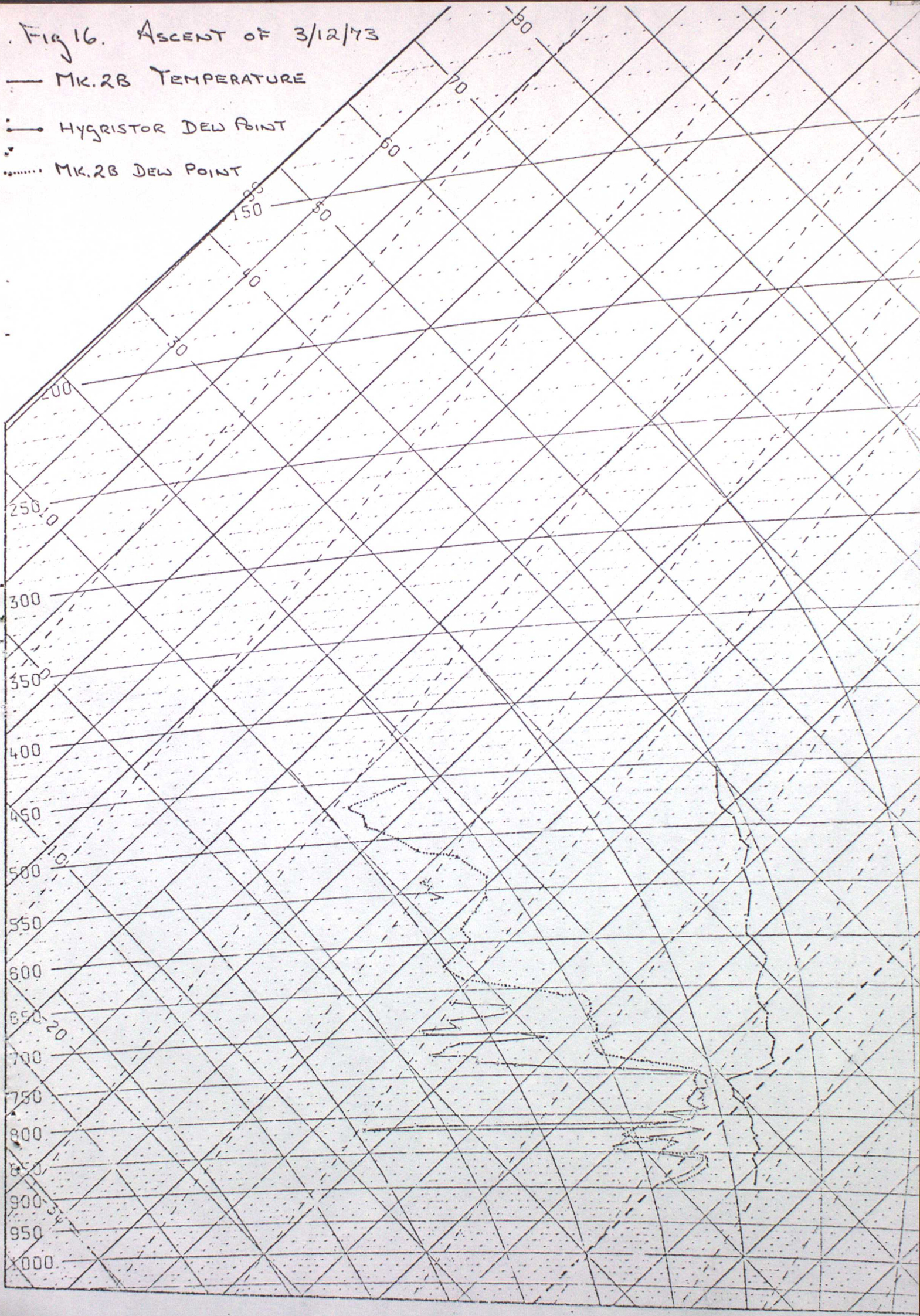




Fig 17

ASCENT OF 22/1/74  
COMPARISON OF TWO HYGRISTORS

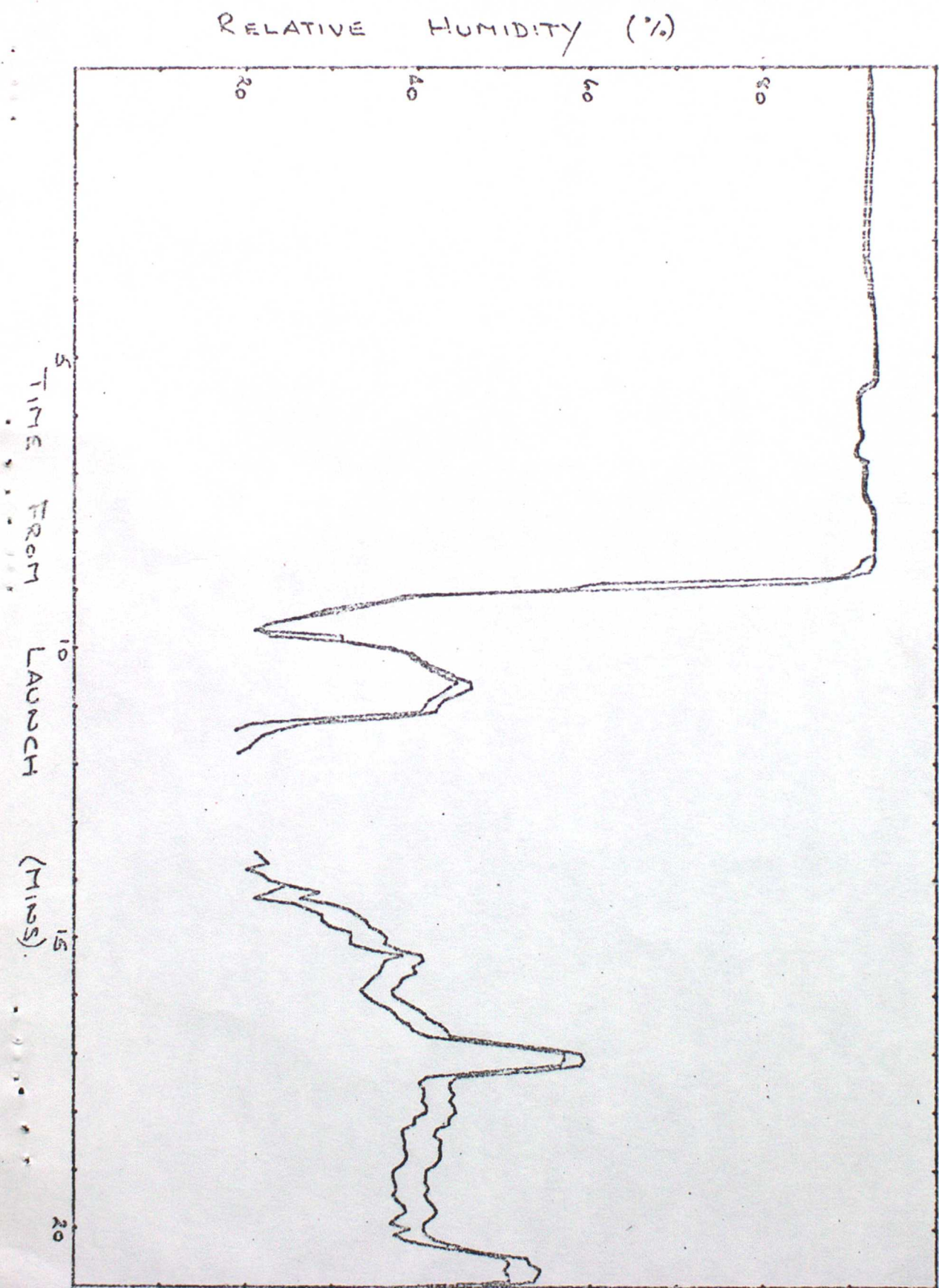




Fig 18

ENLARGMENT OF A SECTION OF FIG. 17.

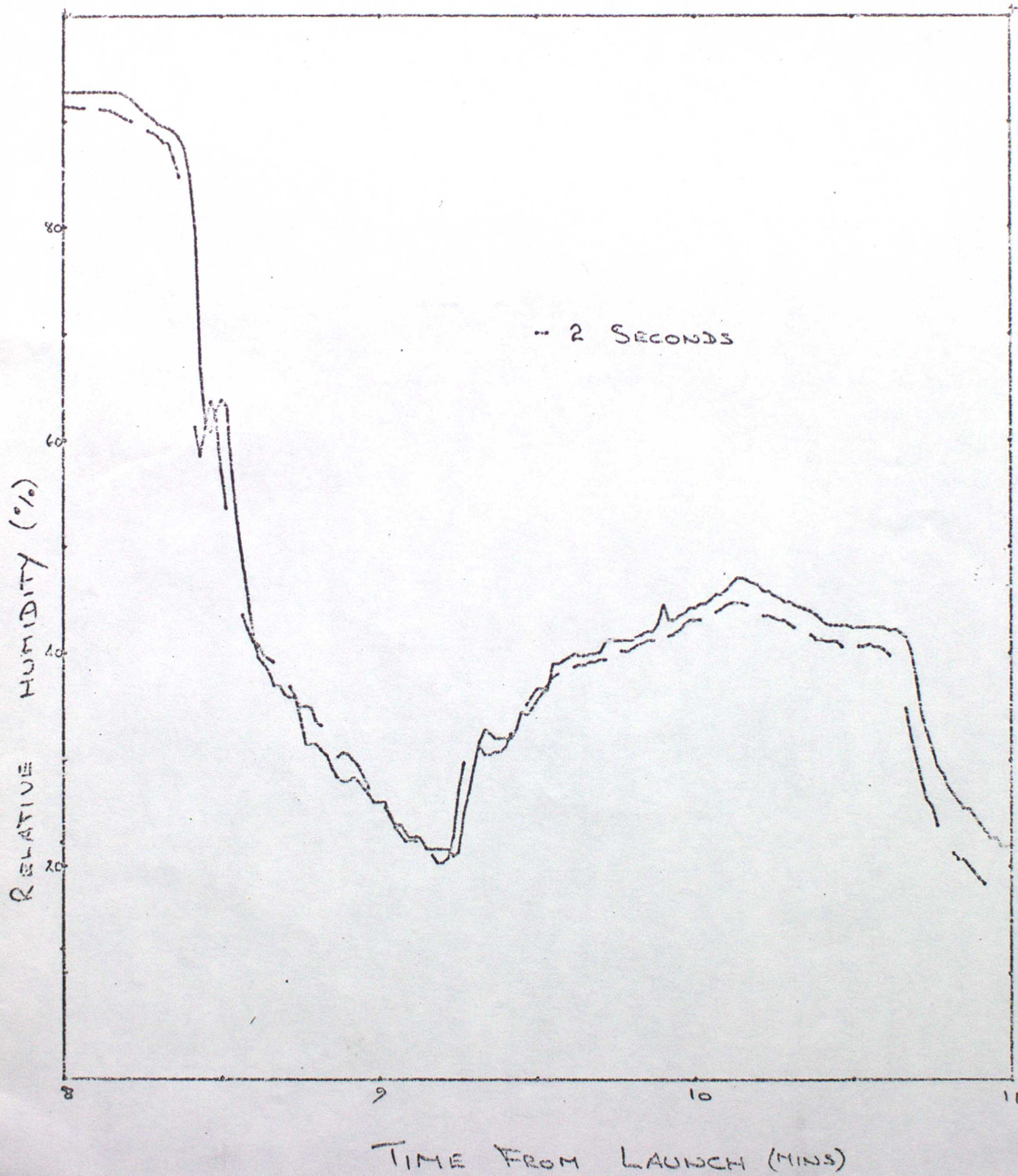




Fig. 19. Ascent of 22/1/74

— MK 2B TEMPERATURE

HYGRISTOR DEW POINTS

----- MK2B DEW POINT

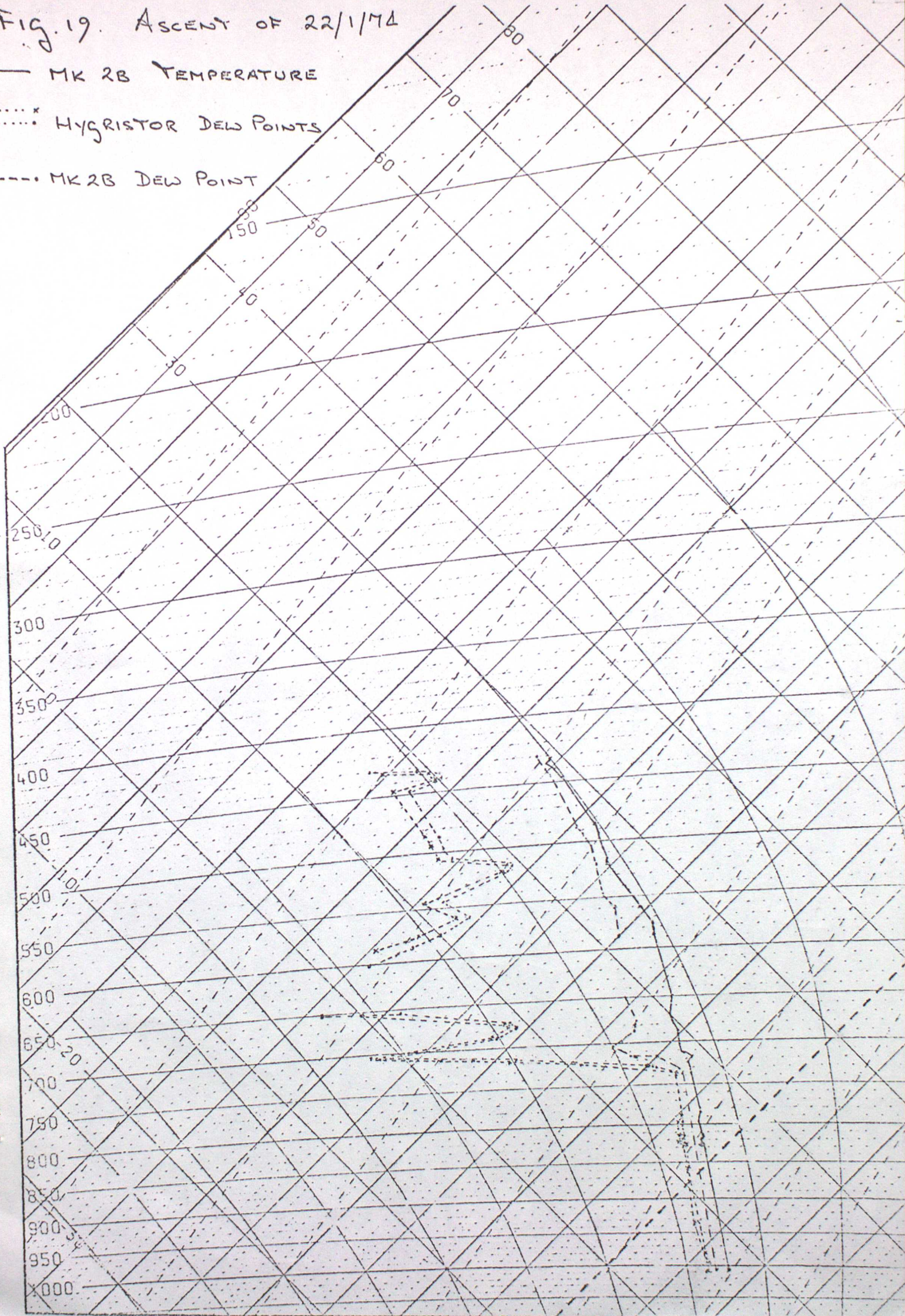




FIG.20. RATE OF CHANGE OF WET BULB POTENTIAL TEMPERATURE WITH RESPECT  
TO RELATIVE HUMIDITY AS A FUNCTION OF TEMPERATURE

RATE OF CHANGE OF WET BULB POTENTIAL TEMPERATURE  
WITH RESPECT TO RELATIVE HUMIDITY AS A FUNCTION

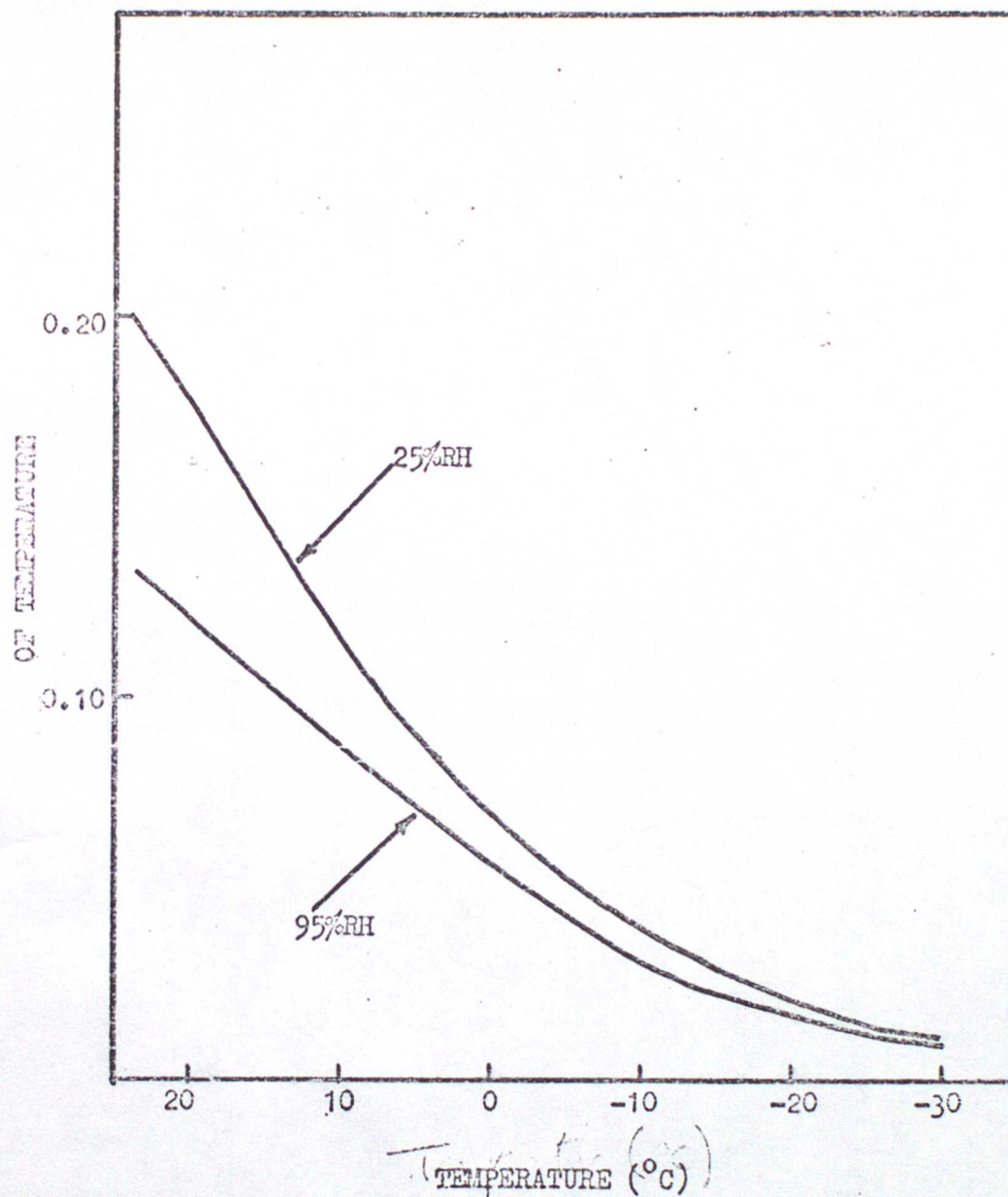




Fig 21 Ascent of 1/10/73

WET BULB POTENTIAL TEMPERATURE

— HYGRISTOR

- - - MK. 28.

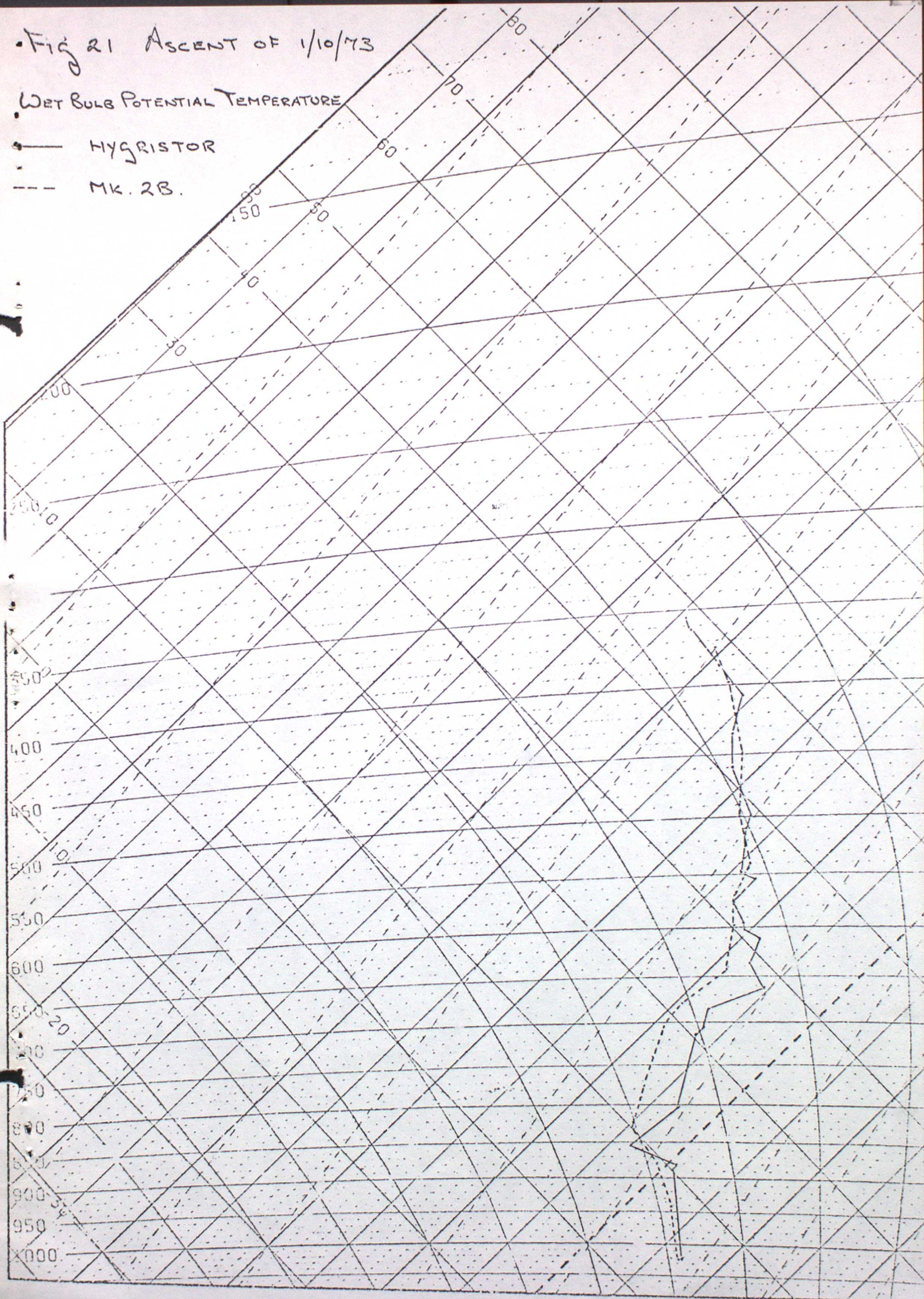




Fig 22. Ascent of 3/12/73

WET BULB POTENTIAL TEMPERATURE

—•— HYGRISTOR

--- MK 2B

