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AN AIRCRAFT DROPSONDE FOR ATMOSPHERIC SOUNDING

by

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An aircraft dropsonde for atmospheric sounding

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Following successful attempts to study the fine structure and dynamics of certain weather systems (Hardman et al, 1972; Browning et al, 1973), in 1972 the UK Meteorological Office decided to develop an aircraft dropsonde capable of measuring ambient temperature, humidity, pressure and wind. The sondes were to be used to obtain a sequence of atmospheric soundings at a set of grid points in a chosen weather system, anywhere within a large operational area over the North Atlantic. This replaced the previous approach, which required a suitable system at the required state of development to pass a specially manned and instrumented, land based field site. The design requirements were set by the desire to use the sonde in such studies, whilst achieving an effective independence of special ground based facilities.

Since that time the design, development and production of a suitable sonde has been achieved in parallel with that of necessary instrumentation and a safe, effective sonde ejector for the Meteorological Research Flight C130 aircraft. Evaluation trials of the complete system were conducted in 1978. The first, preliminary study of a meteorologically significant feature took place over the North Atlantic in March 1979. Further investigations are planned.

The dropsonde

A sketch of the sonde is shown in figure 1. It is in the form of a cylinder of length 84 cm, and diameter 12.5 cm. The overall weight is 3.5 kg. Release from the aircraft sets a winch in motion which withdraws the parasheet ripcord and turns on the UHF transmitter. The body of the sonde is divided in its mid-section by a polypropelene insulator so that the two halves of the sonde act as the elements of a UHF dipole. A spring loaded drogue is used to pull out the main parasheet before falling away to leave the sonde suspended beneath an aerodynamically clean canopy. The average terminal velocity of the sonde from 30,000 ft to the surface is approximately 12 ms^{-1}. The transducers for measuring temperature and humidity are located within a small duct at the downward facing end of the sonde.

A thermistor, with a time constant of about 1 second at the achieved ventilation rate, is used to sense the air temperature. The sonde can experience a thermal shock of the order of $-70^{\circ}C$ when it is ejected at 30,000 ft. Measurements are required as soon as possible after ejection when the body of the sonde at least, is far from thermal equilibrium with its surroundings.

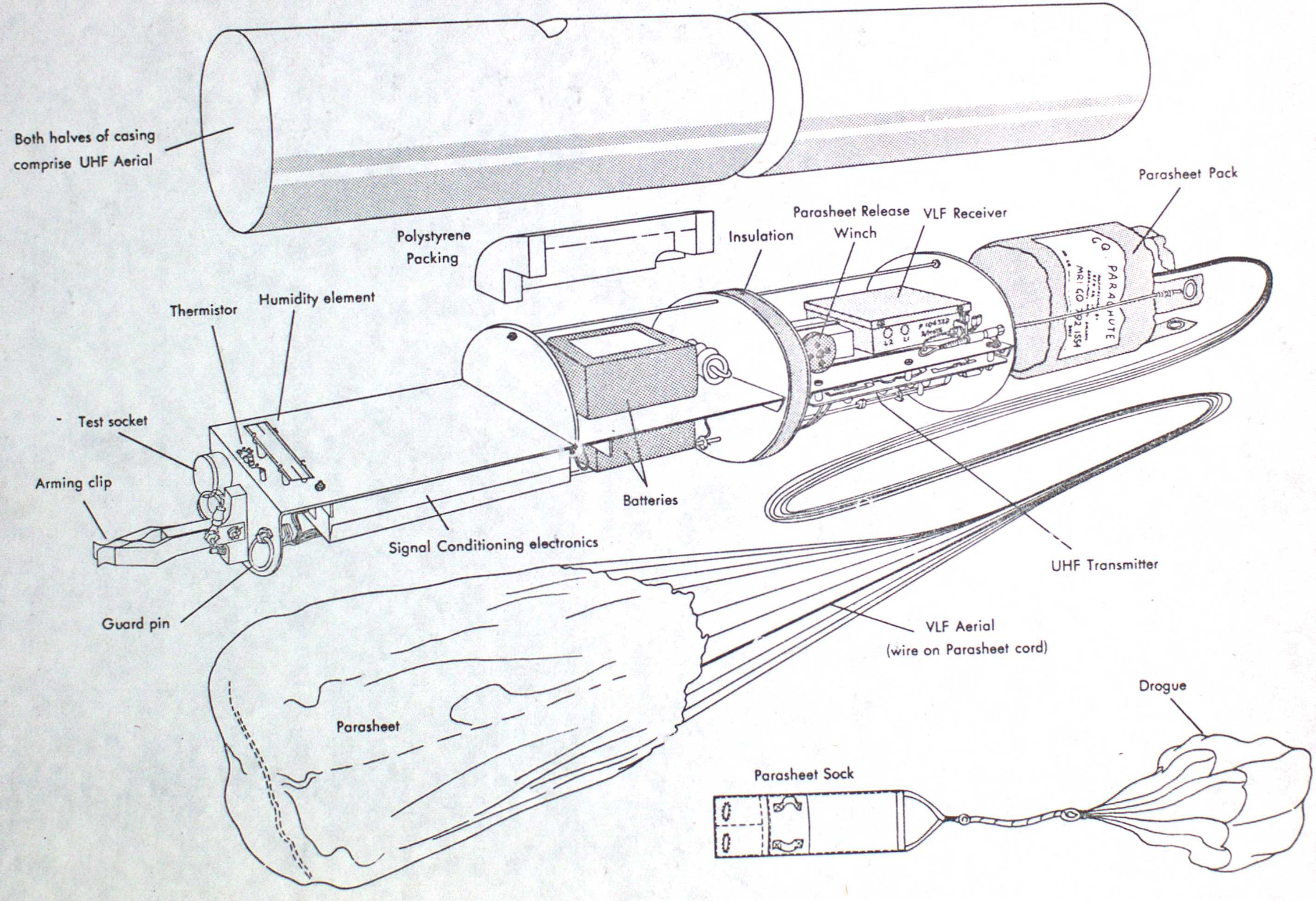

Figure 1 The NAVAID dropsonde

The ability of the sonde to measure the magnitude and direction of the wind during the descent is an important requirement. Such information from a sequence of sondes is necessary to infer regions of vertical motion, and hence those areas likely to produce cloud and precipitation. The expected scale and magnitude of such motion fields demands measurement of horizontal winds, averaged vertically over 600 m or so, to $\pm$ 0.4 ms^{-1} or better.

A guide surface parasheet was chosen as a result of comparative tests to establish wind following characteristics. Unlike some conventional parachutes this type possesses positive stability and is therefore not prone to 'fly' relative to the air. Given that the sonde responds to and moves with the local wind vector, the problem is one measuring the rate of change of its sequential position. Classically such position finding has been achieved by radar, or optical tracking. Unfortunately these techniques require a very stable reference platform and are essentially short range ($\leq$ 100 km) methods. These characteristics are not compatible with the desire to carry out self-contained aircraft experiments over the North Atlantic. As a result sonde tracking through the re-transmission of the long range navigation aid, 'Loran C', was chosen after a careful ground based assessment of its potential accuracy - see Ryder et al (1972) for example. 'Loran C' consists of a set of powerful transmitters which emit pulses of 100 KHz signal on a common and closely controlled timebase. The difference in time of arrival of signals from two separate but coherent transmitters defines a locus or 'line of position'. In practice this is a vertical plane, except close to either transmitter. Two such time differences obtained from at least three transmitters create intersecting lines of position and hence effectively define a unique plan position. The advantage of this technique for sonde wind finding arises from the fact that such a position can be inferred provided only that time differences are preserved without distortion. In particular, any common signal path such as that between a moving aircraft and sonde is unimportant.

The accuracy with which the wind vector can be defined by this method is a function of the relative position of the transmitters and sonde, and upon received signal strength and stability. Loran C is operated by the US Coastguard in co-operation with host nations. It has been set up to provide an accurate navigation aid in various parts of the world, including the North Atlantic. The predicted wind finding accuracy for that region is shown in figure 2, taken from Ryder et al (1972). These data are based upon ground based measurements of received signal stability and the known transmitter locations. However the predictions have been confirmed in trials at Aberporth and Benbecula test ranges when sondes have been tracked by both radar and Loran C, Ryder (1979).

Thus great care has been taken to ensure that the sensor experiences ambient atmospheric conditions, unaffected by the sonde structure whilst being protected from the heating effects of solar radiation. For example, it has proved necessary to coil the thermistor leads to reduce the effects of heat conduction along them. The difficulty of providing a comparable measurement in the field does not allow a complete statement of the accuracy to be expected under operational conditions, but absolute errors appear to be less than 0.5°C overall.

The humidity element is a carbon hygristor of the type used in the VIZ* radiosonde. The device was chosen after careful evaluation in the laboratory and in field trials - see Gibbs et al (1975). Again exposure is most important; speed of response is a function of ventilation rate, humidity and temperature. Trial results suggest that overall accuracy in the range 30 to 95% RH is better than ± 5% RH.

The pressure transducer is a proprietary integrated circuit device** which consists of a ceramic substrate on which are deposited various active elements. A vacuum reference cell is created by etching a silicon chip. This is sealed by a diaphragm on which are diffused four piezo-resistors. These form a strain gauge bridge on the diaphragm. Together with similarly produced signal conditioning electronics and temperature sensing elements, they generate high level voltages which are functions of pressure, and diaphragm temperature. Trials have shown that the transfer characteristics of the devices, including their temperature coefficients, are stable except for an offset error which varies slowly with time. The sensors are not sensitive to shocks of the type experienced at ejection. Trials in which the pressure altitude of the sonde has been inferred from surface pressure, radar height and sonde-observed air temperature have demonstrated that an operational accuracy of ± 1 to 2 mb is possible. The transfer characteristics of each device are determined in the laboratory and a single point calibration is made shortly before use to achieve this accuracy.

Oscillatory signals, whose frequencies vary monotonically in the range 50 to 1800 Hz with the outputs of the pressure, temperature and humidity sensors, are produced by digital signal conditioning electronics. A stable synchronisation frequency at 2000 Hz is generated in a similar manner. All of these sources are switched electronically in turn to frequency modulate the the UHF transmitter. The commutation cycle is repeated every 1.2 seconds.

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* VIZ Manufacturing Co, Philadelphia, Penn, USA.

** National Semiconductor LX1602A.

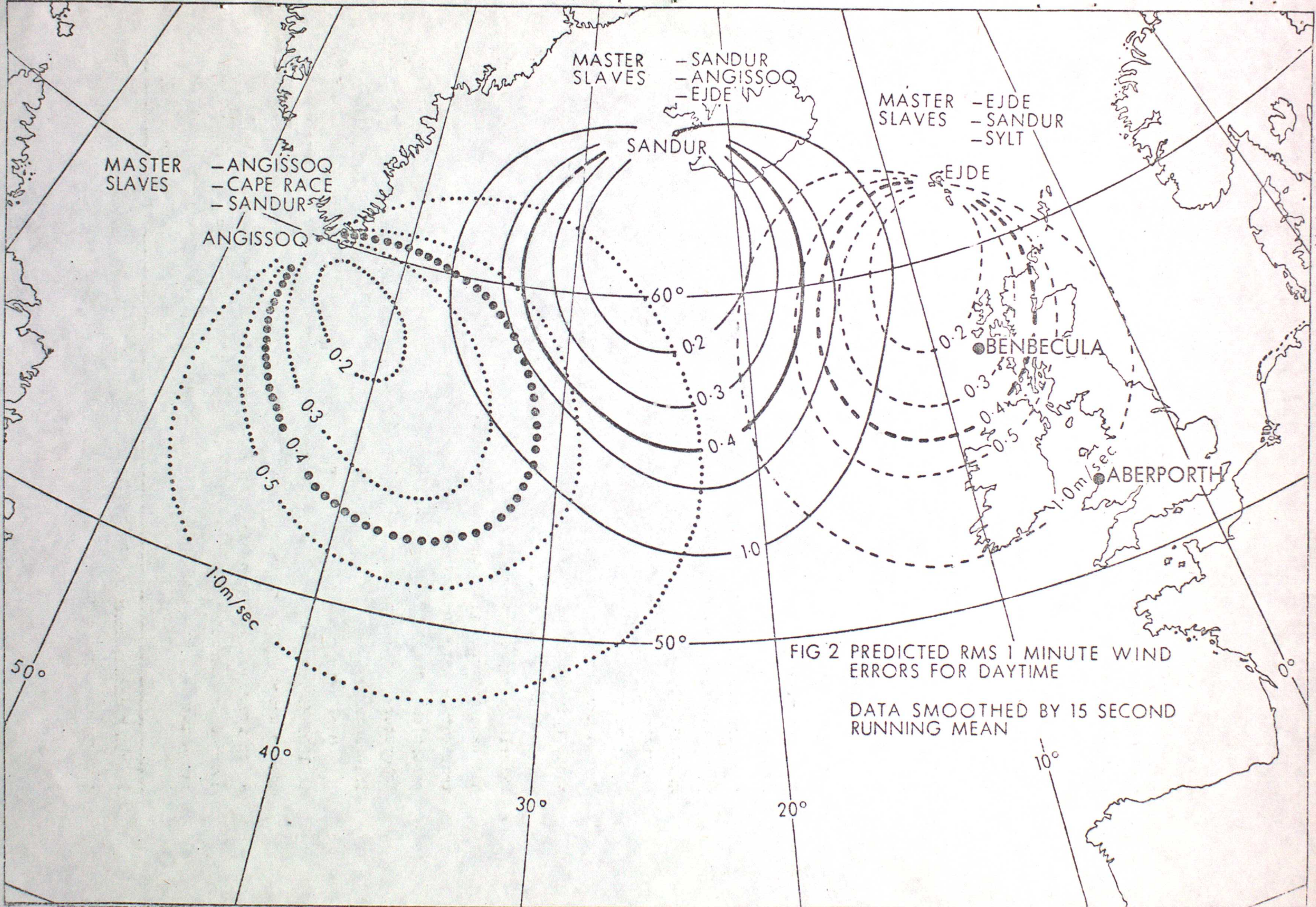

FIG 2 PREDICTED RMS 1 MINUTE WIND ERRORS FOR DAYTIME

DATA SMOOTHED BY 15 SECOND RUNNING MEAN

The Loran C aerial on the sonde is formed from a thin wire attached to one of the parasheet shroud lines. This feeds a tuned LF receiver, whose output is used to frequency modulate the UHF transmitter. The frequency separation between this source and the commutated pressure, temperature and humidity sources is sufficient to prevent mutual interference.

The aircraft instrumentation

Equipment on the aircraft is required for three basic functions. Firstly, to test and perform simple calibration checks on the sonde before use, secondly to store sondes for use and to eject them safely when required, and thirdly to receive, process and store data from the sondes*.

The testing of sondes is carried out on a purpose built rig through the sonde test socket (figure 1). All data are available for scrutiny during a test and are also stored on magnetic tape for subsequent analysis. The rig is used in the laboratory for the calibration of sensors and their signal conditioning electronics before their incorporation into sondes, and on the aircraft to allow a single point calibration at cabin pressure shortly before use.

The dropsonde ejector is a hydraulically operated, spring loaded device in the rear ramp door of the C-130 aircraft. It ejects sondes with their long axis parallel to the aircraft wings. A seal is provided to allow use when the cabin is pressurised. A nearby storage rack allows up to 80 sondes to be carried on a sortie. The ejector has been tested extensively and the facility incorporates several monitoring features including a rearward facing TV camera, to verify satisfactory ejection.

The aircraft is fitted with a down - ward facing broad band UHF receiving antenna, which feeds a suitable preamplifier. Each sonde transmits at one of five separate crystal controlled frequencies in the 400 MHz band. By using receivers tuned to one of each of these frequencies, data from up to five sondes can be processed simultaneously. This is a very valuable capability when frequent soundings are required; to study features on the scale of 10 to 30 km for example. The audio frequency signals from each of these five sources is separately detected, decommutated, digitised and provided as inputs to a 32 k memory computer.

The aircraft receives Loran C transmissions directly as a so-called 'local' signal as well as from the five 'remote' sonde sources. In each case the signals are amplified to limiting to provide an in-phase square wave. The time of arrival (TOA) of one zero crossing in each of the eight repetitive

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* Hardware and software for this latter purpose has been purchased from Beukers Labs Inc, Philadelphia, Penn, USA.

Loran C pulses is measured against a stable internal clock. Each such group of zero crossings is effectively tracked by a second order error detection algorithm in the computer to provide a continually updated assessment of the TOA. The characteristics and optimisation of this technique have been discussed by Ryder (1976). Time differences are formed by straightforward subtraction of the relevant TOAs. The 'local' source provides a suitable first estimate of the times of arrival of the 'remote' sources immediately after sonde ejection. This ensures that stable tracking and hence useful information is available as soon as possible after a sonde is released. Acquisition of the optimum zero crossings of the 'local' signal is obtained at leisure under a combination of automatic and manual control before the sonde dropping sequence is entered. Of course the 'local' source also provides a valuable means of tracking the aircraft. A post flight record of the C-130 ground position is produced as a matter of routine by this method. Individual time of arrival estimates are formed from each of the tracked signals from each of the sondes once per second and are stored with the digitised audio frequency data on magnetic tape for subsequent analysis. Various analogue signals are produced by digital to analogue converter for real time display on chart recorders.

System performance

A typical sonde temperature/humidity/pressure data set is shown in figure 3, plotted as profiles of temperature and dewpoint on a tephigram. The simultaneously observed variations of the westerly and southerly components of the wind are presented in figure 4. These data were obtained at 57°50'N, 15°21'W on 29 March 1979 when the sonde was dropped through a warm front, which was orientated north-south and reached the surface at about 16°30'W at the time of the observation. The aircraft was flying at a pressure altitude of 393 mb and dropped a sequence of sondes in a line perpendicular to the front. The sonde, E008, was one of that sequence.

The temperature vs pressure and dewpoint vs pressure data shown in figure 3 are plots of all the derived data connected by continuous and pecked lines respectively. No smoothing, interpolation or selection of significant points has taken place. Clearly the temperature measurement approaches the environmental value very rapidly. Earlier comparisons between radiosondes and dropsondes suggest that errors are less than 0.5°C within 30 seconds of ejection. (418 mb on this occasion). It is difficult to estimate when the humidity measurement can be assumed to be representative of the environment but as can be seen from figure 3, the estimate has stabilised by 470 mb,

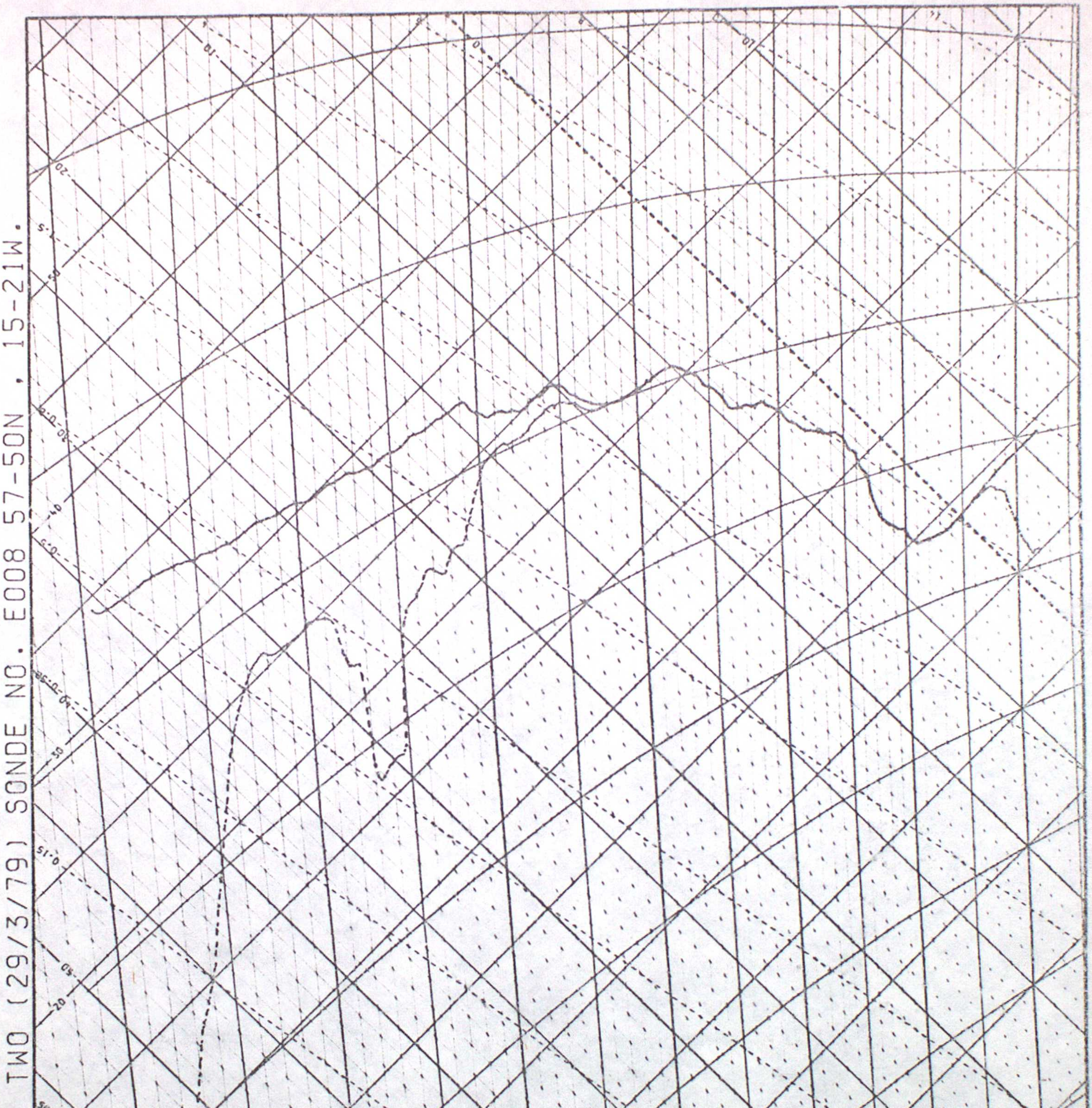

Figure 3. Temperature and dewpoint profiles inferred from typical sonde data

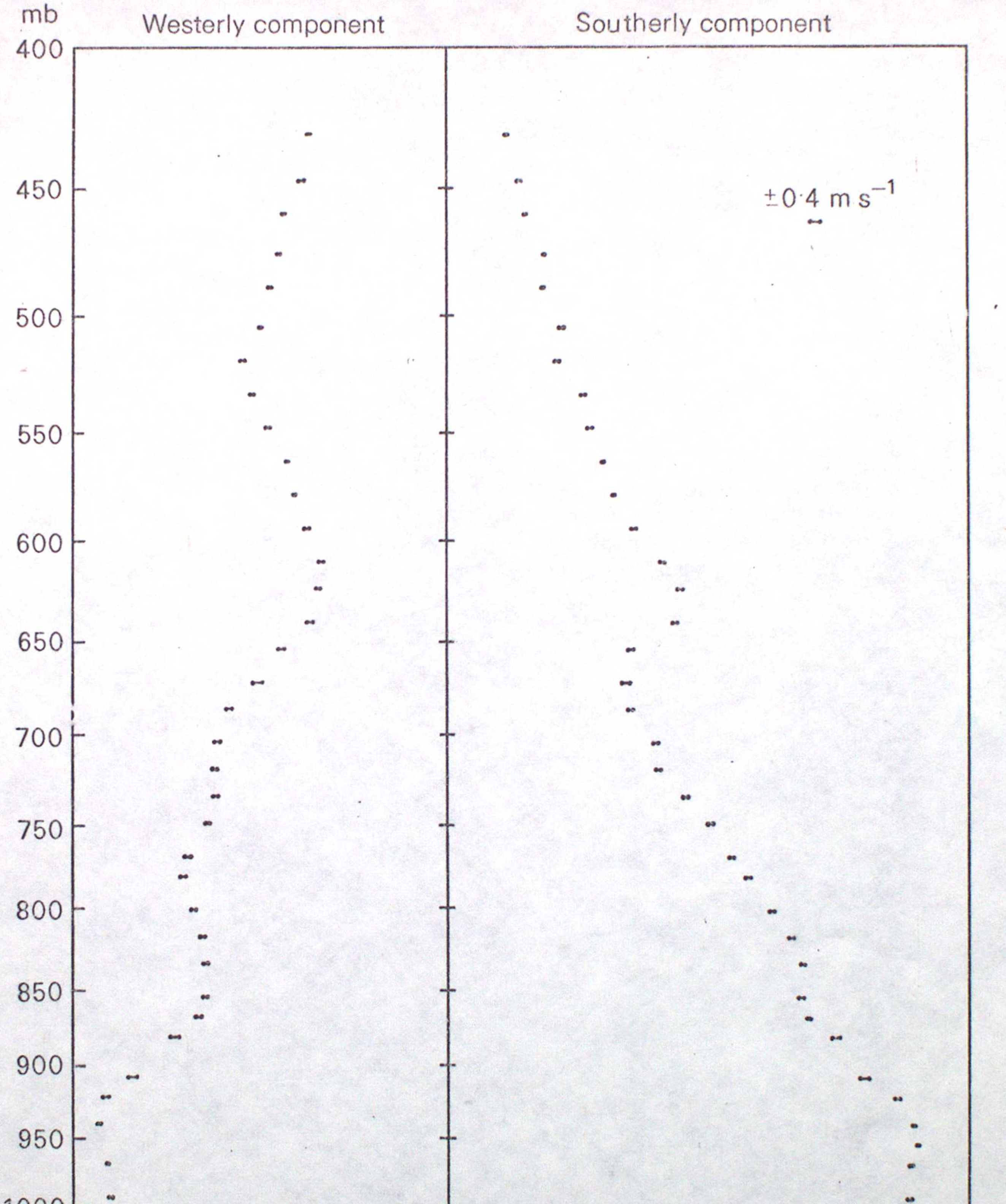

Figure 4. Variation of wind components with altitude. Sonde E008. 29.3.79

90 seconds after ejection. Some part if not all of the earlier variation may be real of course. The dry zone between 510 and 550 mb is a feature of all the sondes in the sequence although its altitude varies with position. Quite sharp gradients are well resolved. The frontal zone extends from 700 to 900 mb and separates air masses characterised by wet bulb potential temperatures of some 11°C and 2°C. The sonde must have experienced significant icing in cloud extending from 680 mb downwards. The humidity data suggests that cloud base is at 965 mb whilst the temperature lapse rate is more consistent with a base at 940 mb. The difference probably represents the time taken for the humidity sensor to recover from prolonged exposure to sub-freezing, saturated conditions.

The wind estimates are obtained from the appropriate rates of change of position calculated by assuming a constant time difference gradient over 60 seconds of Loran C data. An estimate is output every 15 seconds so that successive data points in figure 4 are not independent. Error bars are determined from the goodness of fit of the individual 1 second Loran C data points. Note that these errors are within the predicted windfinding accuracy for this region of the North Atlantic.

The wind profiles so produced are consistent with the expected increase with altitude of the thermal wind component parallel to the front. Synoptic analysis of the feature suggests that it was moving eastwards with a speed of 10 to 12 ms^{-1}. This is in agreement with observed westerly component in the vicinity of the frontal zone. The expected overrunning of the low level cool air by warmer air aloft is also clearly demonstrated by the data. The strong shear at 650 mb is associated with the temperature inversion at that altitude; close inspection of figures 3 and 4 suggests that several other significant features are correlated in a similar and plausable manner. The meteorological significance of the sequence of sonde observations will be assessed elsewhere.

Further developments

The long term reliability of the sonde and aircraft system remains to be demonstrated and as pointed out above there is evidence that the humidity sensor may take some time to recover from prolonged exposure to the combination of low temperatures and saturated conditions. Nevertheless the necessary tools now exist to carry out desired studies of weather systems over much of the North Atlantic.

As configured at present, data from up to five sondes are received, processed and stored on the aircraft for post flight analysis. It is likely that sufficient computing power exists in the aircraft system to produce a real time analysis of the data from one sonde. Such a facility would be a useful addition to those available on the MRF C-130, and to any other suitably equipped aircraft, in carrying out meteorological reconnaissance duties. The feasibility of such a development will be assessed in the near future.

Acknowledgement

The development of this facility represents the combined efforts of numerous members of the Meteorological Office Cloud Physics Branch and the Meteorological Research Flight. Their contribution is gratefully acknowledged.

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