A RADAR SONDE SYSTEM FOR UPPER AIR MEASUREMENTS

The measurement of upper air conditions is an important branch of meteorology because information is required for research, for weather forecasting and for aircraft operation. Although the first soundings were made in the 18th century, using kites and manned balloons, the systematic measurement of air conditions at great heights has become possible only since the development of radio and radar. The development of radio and radar sonde equipment is therefore one of the most significant advances in meteorological instrumentation.

Station of the wind vector as a function of height. Temperature, pressure and humidity are measured and recorded at the ground station at approximately 100 m intervals of the height of the sonde.

For each sounding, an airborne unit (which in a large percentage of soundings is not recovered) is carried into the upper atmosphere by a free, hydrogen-filled balloon. This unit (fig. 1) contains a small combined transmitter and receiver with auxiliary equipment and instruments for measuring temperature, pressure and humidity. The transmitter allows the telemetering of these data during the whole ascent, until the bursting of the balloon, which may occur after it has reached a height greater than 80,000 feet and travelled a distance of over 100

In the following note, a short description will be given of a radar sonde system which has been developed by the Mullard Research Laboratories, Salfords (England), in conjunction with the Royal Radar Establishment, Malvern, for measurements of wind speed, wind direction, temperature, pressure and humidity at heights up to at least 24 km (80,000 ft) 1). The equipment is automatic in operation and provides continuous records at a ground

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A. L. Maidens, Sounding the upper atmosphere, Discovery 18, 156-160, 1957 (No. 4).
Fig. 2. Left: the aneroid barometer; right: the fine-wire resistance thermometer; centre: the skin hygrometer. The aneroid and hygrometer are conventional elements, but the thermometer is a considerable improvement over earlier types. It is constructed with fine, coiled-coil, tungsten wire, has a very short time constant and a very small radiation error at high altitude.

Fig. 3. The Yagi array transmitting the 50 kW interrogating pulses of 2 m waves is mounted on a common pedestal with the receiving aerial, a 5 ft diameter parabolic reflector with nutating dipole. They are automatically kept aligned on the balloon.

The airborne centimetric transmitter contains a triode transmitting valve, controlled by a blocking-oscillator modulator and mounted in a coaxial cavity designed to facilitate large-scale production. The transmitter aerial is an unipole with counterpoise (fig. 1). The power supply of the sonde comprises three primary cells and a vibrator.

The ground equipment is divisible functionally and physically into two groups. The radar group is concerned with the interrogation of the airborne unit, reception of the return signal and determination of the basic positional data (azimuth angle, elevation angle and slant range of the balloon as a function of time). The computer group continuously translates the positional data into wind speed and direction, decodes the telemetering signal and records all the results in graphical and printed form.

The radar equipment is illustrated in figs 3 and 4. The transmitting aerial (a Yagi array) and the thus transmits back to the ground a pair of pulses for each interrogating pulse, the time delay between the two pulses of a pair representing the reading of the meteorological instrument. The control voltages of the three instruments are brought into operation in sequence by a motor-driven switch, so that each instrument reading is encoded once every 17 seconds.

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receiving aerial (a parabolic reflector) are mounted on a common pedestal driven by a motor servosystem. The receiving aerial is fitted with a nutating dipole which produces a conical scan of the narrow aerial beam and superimposes a modulation on the received signal when the aerial is incorrectly aligned. This error signal steers the servosystem so as to give accurate automatic following of the balloon in direction. The microwave receiver, which is equipped with automatic gain and frequency control, amplifies the signal from the balloon and delivers it to the automatic ranging system and the telemetering system. The ranging system is of a novel type in which the rotation of a motor-driven, phase-shifting transformer is related to the change in distance of the balloon, so that the speed of rotation is an accurate measure of the radial velocity of the balloon (radial wind component). A rotation of $360^\circ$ is equivalent to a change in distance of one tenth of a nautical mile. The phase-shifting transformer, therefore, permits fractions of a tenth of a mile to be measured; full tenths of a mile are determined by counting the number of oscillations of a crystal calibrator occurring between transmitted and responding pulse. The calibrator controls the pulse repetition frequency of the transmitter and oscillates with a time period exactly corresponding to one tenth of a nautical mile in radar range. The received signal is monitored and readings of range $R$, azimuth $\Theta$ and elevation $E$ are provided by a display unit (fig. 4). This unit is also fitted with the manual controls for range and aerial position which are used at the beginning of a flight before the equipment is finally switched over to fully automatic operation.

The continuous computation of the wind vector (which is parallel to the surface of the earth) is effected from the tangential and radial wind components, given by the equations (in spherical polar coordinates):

$$V_T = R \frac{d\Theta}{dt} \cos E,$$

$$V_R = \frac{dR}{dt} \cos E - R \frac{dE}{dt} \sin E.$$
An important feature of these equations is the occurrence of the derivatives of (slant) range $R$, azimuth $\Theta$ and elevation $E$ with respect to time $t$, i.e. the radial and angular velocities. The auto-ranging and auto-alignment circuits are so designed as to provide signals directly proportional to these velocities. The wind computer which determines the vector resultant of $V_T$ and $V_R$ is illustrated in fig. 5. It is an analogue computer employing precision potentiometers for multiplication and magslips (synchros) for trigonometrical computation. The vector amplitude and direction are derived from $V_T$ and $V_R$ in a “triangle-solver” magslip whose rotor shaft assumes a position corresponding at every moment to the wind direction. A 4 ft diameter recording table is directly coupled to this shaft and a recording pen is driven at a constant speed in a radial direction across the table. The pen thus traces out a continuous graph of instantaneous wind direction against time. A voltage proportional to the vector amplitude, i.e. the wind speed, is induced in the magslip rotor coil and is recorded by a conventional recording meter. The height of the balloon, corrected for earth curvature, is computed by similar analogue methods and recorded as a function of time.

The ground telemetering equipment, shown in fig. 6, is designed to identify the coded signals from the balloon, to measure accurately the time delay between the ranging and telemetering pulses and to encode the results in a form suitable for operating a standard teleprinter. The time delay is measured by allowing crystal-controlled timing pulses, with a one microsecond separation, to pass through a gating circuit during a period initiated by the ranging pulse and terminated by the telemetering pulse. The total number of timing pulses corresponding to five hundred pairs of signal pulses is counted by an electronic counter and the average delay is transferred to the teleprinter encoder. The figures are printed by the teleprinter in five columns, each of four digits, corresponding to the three meteorological parameters and two reference signals which are also transmitted by the airborne unit. Coding sig-

Fig. 5. The wind computer. A magslip turns the rotatable 4 ft diameter table so that at every instant it has a position corresponding to the computed wind direction. A recording pen moving at constant speed along the fixed radial arm traces out a graph of wind direction as a function of time (cf. fig. 7).

Fig. 6. The telemetering console. The left-hand unit contains wind-speed and height recorders, the right-hand unit encoders and temperature, pressure and humidity recorders and the centre unit a digital computer and teleprinter.
nals interposed in the airborne unit switching sequence are used to ensure that the results are printed in the correct columns.

Some typical flight records, which are self-explanatory, are shown in figures 7, 8 and 9. The equipment is designed to measure wind speed with an error not exceeding 5 km/hr. The telemetering channels are designed for an error of the order of 0.1%, but at present the meteorological instruments themselves contribute somewhat larger errors.

Fig. 7. A typical wind direction record obtained from the radar sonde system.

Fig. 8. Typical teleprinter record obtained from the radar sonde system.
The prototype equipment is at present undergoing flight trials to assess its suitability for routine soundings and research.

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