AN INSTRUMENTED GLIDER FOR METEOROLOGICAL RESEARCH

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SUMMARY

The instrumentation of a Slingsby T-53B glider for meteorological research purposes is described, together with a computer compatible logger for 14 data channels. Sample outputs from the initial part of the system are shown.

The Natural Environment Research Council has provided Reading University with a glider which is being instrumented for meteorological research purposes. The aircraft, a Slingsby T-53B, was collected in October 1969. Since then, a part of the designed instrument system has been installed, the aircraft's performance tested (Ref. 1), and a number of meteorological flights made. To date, circumstances have not provided us with a clear-cut mesoscale meteorological system to investigate within our limited range, and this paper is to be regarded purely as a report of work in progress, without presenting new scientific results.

METEOROLOGICAL AIMS

There are a number of meteorological problems in the planetary boundary layer which, for their elucidation, need observations on a smaller scale than has been possible to date. These include:

1. The structure of, and the vertical heat transfer by, individual thermals.
2. The distribution of thermals over a fairly uniform area to give an estimate of the average vertical heat and water vapor fluxes. Data on this should also give information of the changing organization of thermals with height and the heat flux divergence.
3. The development and structure of those sea-breeze fronts which penetrate well inland as density currents.
4. The mixing across "discontinuities" in the atmosphere such as the sea-breeze front or in entraining thermals.

For the professional meteorologist, the measurement of the fluxes on a convective day is the most significant of these problems because of the information the results will give on the inputs to large-scale dynamical models at the lower boundary; but all the problems are of topical interest.

For the observation of air motions and other variables every few meters along a path which can be related to the structure under investigation, a slow-moving aircraft is the obvious vehicle. A glider has the characteristics of stable flight at slow speeds and of known performance in still air so that its own motion can be used almost directly as a measure of the air motion. It is more responsive to changes in vertical air motion than in horizontal (Ref. 2), and it samples the air with the minimum of disturbance. The economic advantages are great, particularly in circumstances where lift is present to provide free flying time, and finally we would stress the enormous advantages of operating in a gliding environment where we can draw freely on the experience and the actual observations on experimental days which is provided by skilled pilots; undoubtedly the best observers of the scale of feature we are investigating. The disadvantages of using a glider in systematic investigations of any sort are well known. We believe that the ideal vehicle is in fact a powered glider, and the specification of our ideal is included as an appendix. To date we have not managed to obtain or develop this vehicle, but the choice in this field is improving.

INSTRUMENTAL REQUIREMENT

To study any of the problems listed above, we need to know the vertical air velocity, temperature, humidity, height, and position in detail small compared to the dimensions of the system we are looking at. For a thermal 100-m across or for the detail of the sea-breeze frontal surface, observation every 2 m along the flight path may be desirable, but the limitations of data logging and handling have led us to accept a minimum sampling interval of about 0.4 sec initially, which corresponds to a distance of 8.5 m at our normal cruising speed of 21 m/s. (This is about the airspeed for minimum sink, and hence minimum variation of sink speed with airspeed.)

To measure the vertical air velocity at this interval, we shall measure the angle of attack with a vane mounted on a short-nose boom; the aircraft motion with an accelerometer; and the pitch angle from a gyro. Temperature and humidity will also be sampled frequently (though we have the usual problems with rapid humidity measurement), while other variables need only be sampled at longer intervals. These include static pressure, airspeed, roll angle, heading, and variometer output.

THE DATA LOGGER

The system is an elaboration of that described by one of us (Ref. 3). The specification of the full system is shown in Table 1. At present, the whole data logger is in operation, but only half the sensors and transducers are built.

A portable two-track tape recorder (Uher 4400S) is used, and the output from six sensors logged every 1.638 sec on one track and the outputs from the other eight sensors (a maximum figure), together with speech, is recorded on the other. Each sensor has its own transducer whereby changes in the parameter vary the audio frequency of an oscillator through either capacitative or resistive changes. The audio range obtainable is typically an octave and in the range 5 kHz to 13 kHz. The method of recording is to use a set of electronic switches all controlled by one crystal (conveniently oscillating at 5 kHz). Each sensor's output is recorded for an accurately known time, and, in playback, the frequency is deduced by counting the oscillations recorded in this known time. Two vital advantages of the method are that the tape's playback speed does not need to be identical with the recording speed, and that the counts are already digitized and can be put onto punched tape or into a computer directly.

The duration for recording any particular output is most conveniently achieved by repeatedly doubling the period of the crystal's oscillation (1/5000 sec). For the quantities to be sampled frequently, 0.051 sec is an appropriate member of the series, and this gives a possible count ranging from 358 to 768; hence a resolution of 1 part in 400 of a full scale. The quantities in the second group, for which a greater resolution is needed, need only be sampled less frequently and for a longer duration. Adequate information will be derived if the parameters on Track 1 are sampled every 1.638 sec and those on Track 2 about once every 0.410 sec. Voice, or other low-frequency information, can be recorded on either track below 7 kHz.

TABLE 1. GLIDER INSTRUMENTATION SYSTEM

PARAMETER	REQUIRED FOR	METHOD OF MEASUREMENT	DESIRABLE			DESIGNED SYSTEM		
			RANGE	ACCURACY	SAMPLING INTERVAL (SEC)	SAMPLING TRACK 1 (SEC)	DURATION TRACK 2 (SEC)	MAX. COUNT RANGE
STATIC PRESSURE	HEIGHT	ANEROID	0-5000 m	0.5 m	1.0	0.819		4,096 - 16,608
DYNAMIC PRESSURE	AIRSPEED	ANEROID	0-50 m/s	0.5 m/s	1.0	0.051		255-663
VERTICAL ACCELERATION	INTEGRATE FOR VERTICAL VELOCITY-RAPID VARIATIONS	INERTIAL ACCELEROMETER	0-2 g	0.01 g	0.1		0.051	255-663
PITCH ANGLE (OR RATE)	CORRECTIONS TO VERTICAL AIR MOTIONS (W)	GYRO	±5 deg	0.05 deg	0.1		0.051	255-663
ROLL ANGLE (OR RATE)	SECOND ORDER CORRECTION TO W	ARTIFICIAL HORIZON	±45 deg 5 deg/sec	0.5 deg	1.0	0.051		255-663
ANGLE OF ATTACK	VERTICAL AIRSPEED	WIND VANE	±10 deg	0.1 deg	0.1		0.051	255-663
HEADING	MANEUVER CHECK	COMPASS	0-360 deg	1.0 deg	10.0	0.051		255-663
TEMPERATURE	BUOYANCY, HEAT FLUX, AIR MASS IDENTIFICATION, ETC.	THERMISTOR 1	-5 to +25°C	0.01°C	10.0	0.205		1020-2652
		THERMISTOR 2	±5°C	0.02°C	0.1		0.051	255-663
HUMIDITY	WATER VAPOR FLUX, AIR MASS IDENTIFICATION, ETC.	INFRARED RADIOMETER OR ABSORPTIOMETER	1-25 mb	5%	0.1		0.051	255-663
		WET BULB DEPRESSION	0-15°	0.1°	0.1		0.051	
VERTICAL VELOCITY	INSTRUMENT CHECK	VARIOMETER (COMMERCIAL)	±5 m/s	0.1 m/s	1.0	0.051		
					SAMPLING INTERVAL	1.638	0.410	
						RESOLUTION ±1 COUNT		

The whole system is flexible and any sensor output can be recorded on any number of channels for particular tests or experiments through pins on a selector panel. So that the observer can have an in-flight visual check, the output from each transducer is monitored by a frequency-to-voltage converter whose output is displayed on a moving coil meter on the rear instrument panel. The sensitivity of these monitors is not such that they will be able to give the observer usable information in flight, but they show that outputs are within reasonable ranges. This is particularly important because the absence of one input on the tape will dislocate the computer program and makes extraction of the other data tedious. Preflight checks include playing back a section of tape at slow speed so that the individual notes can be distinguished.

Much work remains to be done on the system, but the ultimate sensitivity of the height measurement is 1 m. It is sensitive to acceleration to less than 1 m change per g and to temperature to about 1 m per degree Centigrade change. Indicated airspeed is read to ±0.25 ms^{-1} and appears repeatable to 0.5 ms^{-1}, while temperatures show changes of 0.05°C and give absolute values to about ±0.3°C.

The weight of the whole system, including batteries, sensors, recorder and the whole observers instrument panel, is under 20 kg.

SUPPLEMENTARY DATA LOGGER

When considering the limitations of a pure glider's access to regions of interest, it seemed that valuable information could be obtained from a simpler system which could be installed in any powered aircraft which was available to carry out reconnaissance flights. Accordingly, a four-channel version, recording height, airspeed, temperature, and wet bulb depression together with speech, was built and has been used during initial sea-breeze operations. The total weight of this system, including sensors, tape recorder, and batteries, is under 10 kg.

PLAYBACK

The procedure for extracting information from the record is as follows: first the tape is played through and a transcript of the significant speech is made. The sections to be fully analyzed are chosen and these are played back into a PDP 8 computer which is programmed to count and store the number of cycles in each recorded sample together with a serial number corresponding to a section of the tape. All the counts are punched out on paper tape and are then fed into the University's main computer (an Elliott 4130) together with the appropriate calibrations. This converts the counted number to pressure altitude, indicated airspeed, temperature, etc., and will also process the results at the same time to give, for example, potential temperature or humidity mixing ratio, and also to give means over various periods. For the fullest use of the computer, a graph plot of the outputs is called for, but this consumes a disproportionate amount of the computer time and is used less generally than we would like. A sample output and graph is shown in Fig. 1, where every 8th point is plotted.

PROGRESS TO DATE

Most of the sensors and transducers have, of necessity, to be developed in house; by Spring 1970 we had pressure and ASI, using a nose-mounted pilot-static tube, together with a Burton electric variometer, and a variety of temperature sensors in operation. These include a long-period (4-sec exponential response time) thermistor for reference, a wet bulb of similar period, a rapid response thermistor measuring the departure from the long-period thermometer (response time estimated at 0.4 sec), and a miniature wet bulb depression thermometer. Other sensors under construction, or in the planning stage, include the incidence vanes; accelerometer; and pitch, roll, and heading take-off from an air-driven gyro. The additional power required to drive this last item may be large for routine glider operations, but it may be regarded as an instrumental development or interest in its own right. Since April of this year, priority has been shifted to gaining experience in operations and also to providing the portable system mentioned above and to programming the analyses.

OPERATIONAL METHODS

It would be presumptuous of us to present details of operational methods which are untested. We had hoped by now to have some detailed studies of sea-breeze fronts over southern England, following the work of Simpson (Ref. 4) who is collaborating closely with us. The year 1970 has not been climatologically normal in this respect and no well-defined front has so far reached our base at Lasham during our operational period. We plan to follow the progress of the front with the portable system in a powered aircraft and draw a detailed cross section from a rapid descent with the glider.

Convection over southern England has also been poorly organized, but a sample run through a well-defined thermal is shown in Fig. 2.

Figure 3 shows potential temperature plotted against height for this run (Run 3) and a lower run (Run 5) on the same flight.

Thirteen second (i.e., 8 point) means are plotted and Run 5 shows two "thermals" warmer than their surroundings by about 0.25°C while Run 3 appears to show a cool region of thermal just below cloud base.

Our first descent in a number of straight passes through a thermal marked with five or six circling gliders has yet to take place. May it not be our last as well.

REFERENCES

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3. G. R. Whitfield, "A Simple Data Recording System with Computer Analysis," Radio and Electronic Engineer, Vol. 40, pp. 255-258, 1970.

4. J. E. Simpson, "Aerial and Radar Observations of Some Sea Breeze Fronts," Weather, 22, 1967, pp. 306-316.

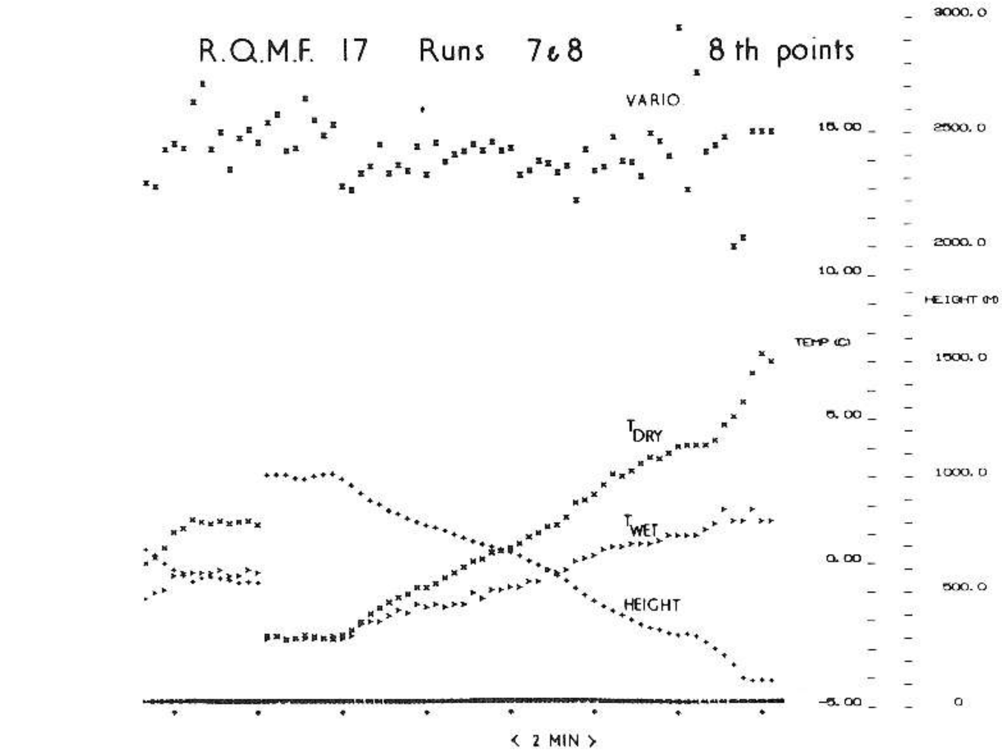

FIGURE 1. SAMPLE COMPUTER OUTPUT. 2 APR 1970. LOW LEVEL RUNS. EVERY EIGHTH POINT PLOTTED

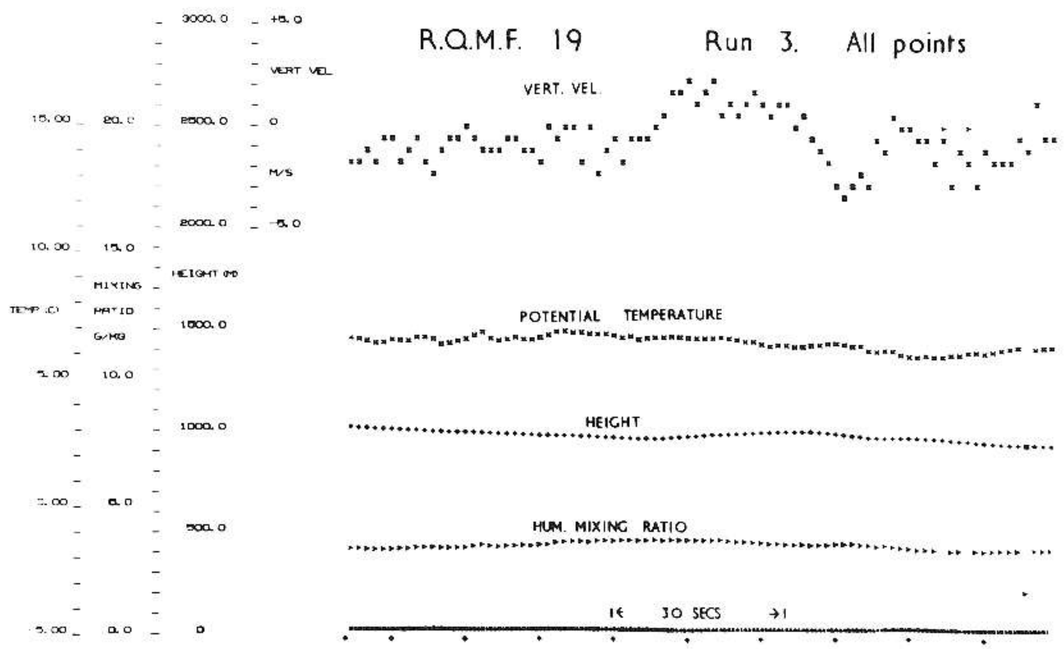

FIGURE 2. SAMPLE COMPUTER OUTPUT. 28 APR 1970 RUN 3 THROUGH THERMAL NEAR CLOUD BASE. EVERY POINT PLOTTED

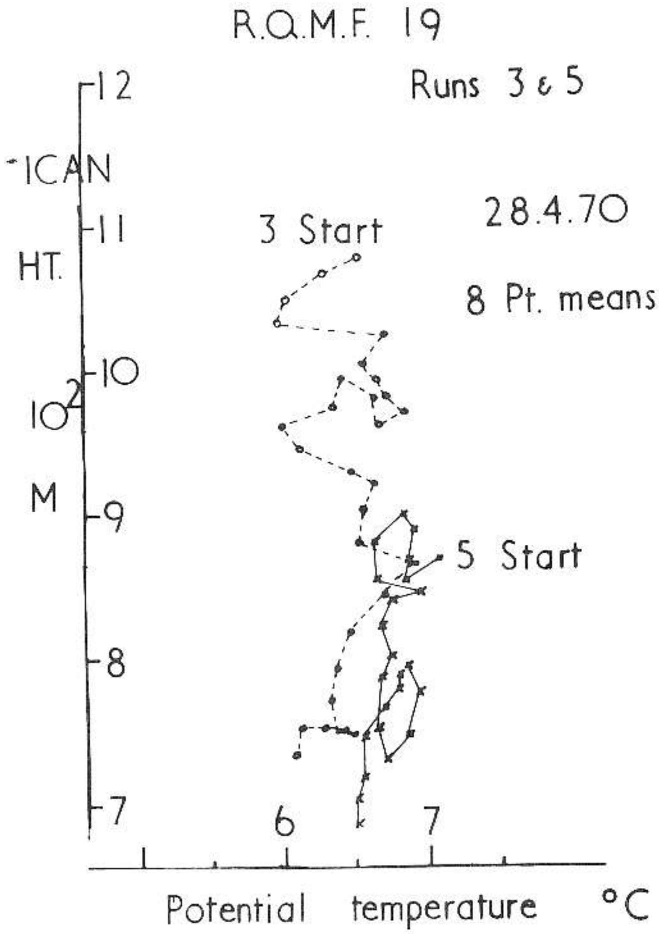

FIG. 3. POTENTIAL TEMPERATURE VS. HEIGHT. 28 APR 1970. RUN 3 THROUGH THERMAL NEAR CLOUD BASE, AND RUN 5 THROUGH TWO THERMALS LOWER DOWN. EIGHT POINT MEANS PLOTTED.

APPENDIX

POWERED GLIDER FOR METEOROLOGICAL RESEARCH

Outline Specification

Low cruising speed with good control and known performance

Safety in turbulent cloud

Clear nose for mounting sensors

Low capital and running costs

2 seats

Adequate instrument payload (70 lb)

Rate of climb greater than 500 ft/min

Endurance of 4 hr

Low noise level