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AN INSTRUMENTED RADIO-CONTROLLED MODEL AIRCRAFT FOR BOUNDARY LAYER MEASUREMENTS

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ABSTRACT

Trials to measure air temperature and the global flux of UV radiation with a radio-controlled model aircraft are described. The technique appears suitable for measurement of temperature (and presumably other scalar variables) up to altitudes of 1.5 km. Global radiation flux profile measurements to the same altitude can be made to a relative accuracy of about 10 per cent. Within this accuracy and height range the global UV flux on clear days has not been observed to vary with altitude, even in the centre of industrial Melbourne.

INTRODUCTION

Investigations of the atmospheric boundary layer often require *in situ* measurements to altitudes of 1 to 2 km. Each technique for obtaining such measurements has its own disadvantages. Aircraft and free-flying balloons are expensive platforms when many profiles are required - as when a detailed time-height picture of a sequence of events is to be recorded. Tethered balloons, kites and kytoons can be relatively cheap since the equipment they carry is recoverable, but must be flown in specific weather conditions. In addition, they are generally subject to severe restriction by aviation authorities. The same is true also for aircraft. Thus in cases when the interest is in an environmental problem of an urban atmosphere, an extensive research program can be incompatible with aviation and general safety regulations.

This paper reports trials of the use of a radio controlled model aircraft as a platform for studies of the lower atmosphere. Occasional references (*eg* Bardeau, 1968) to the use of model aircraft for scientific purposes have appeared in the literature. The technique has several advantages. A model aircraft is highly manoeuverable, it can be "placed" spatially anywhere within sight of the operator, it is itself relatively cheap and the instrumentation it carries is recoverable intact. Perhaps most important, although near-city safety regulations with regard to its use are restrictive, they are not prohibitively so.

Air temperature and the global flux of ultra-violet radiation were measured on the trials reported here. Solar ultra-violet radiation is highly absorbed by various atmospheric pollutants - particularly by the photochemical smog associated with cities, which can become trapped beneath low level temperature inversions (Mosher *et al* 1970; Galbally, 1971). The profile of UV radiation should therefore be related, among other things, to the height distribution of absorbing substance. However, the main interest at this stage was whether useful solar radiation flux measurements in general could be made from model aircraft.

INSTRUMENTATION

The radiation detector was an RCA 922 vacuum phototube mounted beneath and against a 5 mm thick, flat, disc of UG11 filter glass. This tube has a response versus wavelength characteristic which peaks sharply in the UV region at about 350 nanometer (nm), the same as the wavelength of peak transmission of the filter. The tube also has a smaller response peak in the near IR which overlaps a subsidiary transmission band of the filter material. However, the transmittance of 5 mm of the filter material in this band is much less than 1%, and the response of the combination to radiation other than ultra-violet can be neglected.

A phototube detector has the fast time response necessary for the experiment, but is highly directional. In order to obtain a good "cosine" response for the measurement of total downward flux, the upper surface of the filter was coarse-ground to provide a diffusing surface. The filter was covered by a thin sheet of opal glass which in turn was coarse-ground on its upper surface. The error in cosine response of this arrangement was less than 10% out to zenith angles of 75°. The unit was mounted just behind the wing facing upwards.

Temperature was measured by a glass encapsulated NTC thermistor bead - 100 kΩ at 25°C. It was mounted in the shade just below the wing about 10 cm out from the fuselage.

Figure 1 gives the circuit diagram of the equipment. Both the phototube and the thermistor act as variable resistors, whose values determine the frequencies of the multivibrators (Rudge, 1962). The output pulses of the multivibrators are fed directly to a single-track cassette tape recorder via a relay which switches automatically from one to the other (≃ 25 s on UV, 15 s on temperature). The equipment incorporates a baro-switch from a normal balloon-borne radiosonde which causes the temperature signal to change frequency by a fixed amount at specified pressure altitudes. The accuracy of this baro-switch is 2 - 3 mb, so that at points of actual "make or break" of a contact the height can be specified to about 20 to 30 m.

The complete equipment including batteries, weighs just under 1 kg. The tape recorder, a Grundig EN3 which runs for 20 min, accounts for 500 gm of this. After a flight the record is played back into a frequency meter whose output is recorded directly onto chart.

It is worth noting that initial attempts to telemeter the data using a normal radiosonde 403 Mhz transmitter proved disastrous. It was found impossible to prevent the transmission interfering with the radio control. In any event the present method is more suitable when portability is a consideration.

Calibration curves of the two sensors are given in Fig 2. The circuitry is slightly temperature sensitive - in both cases about 0.2% °C. Long-term stability of the sensors and circuitry was not checked rigorously, but two water bath calibrations of the thermistor separated by a period of 5 weeks were identical to within 2%.

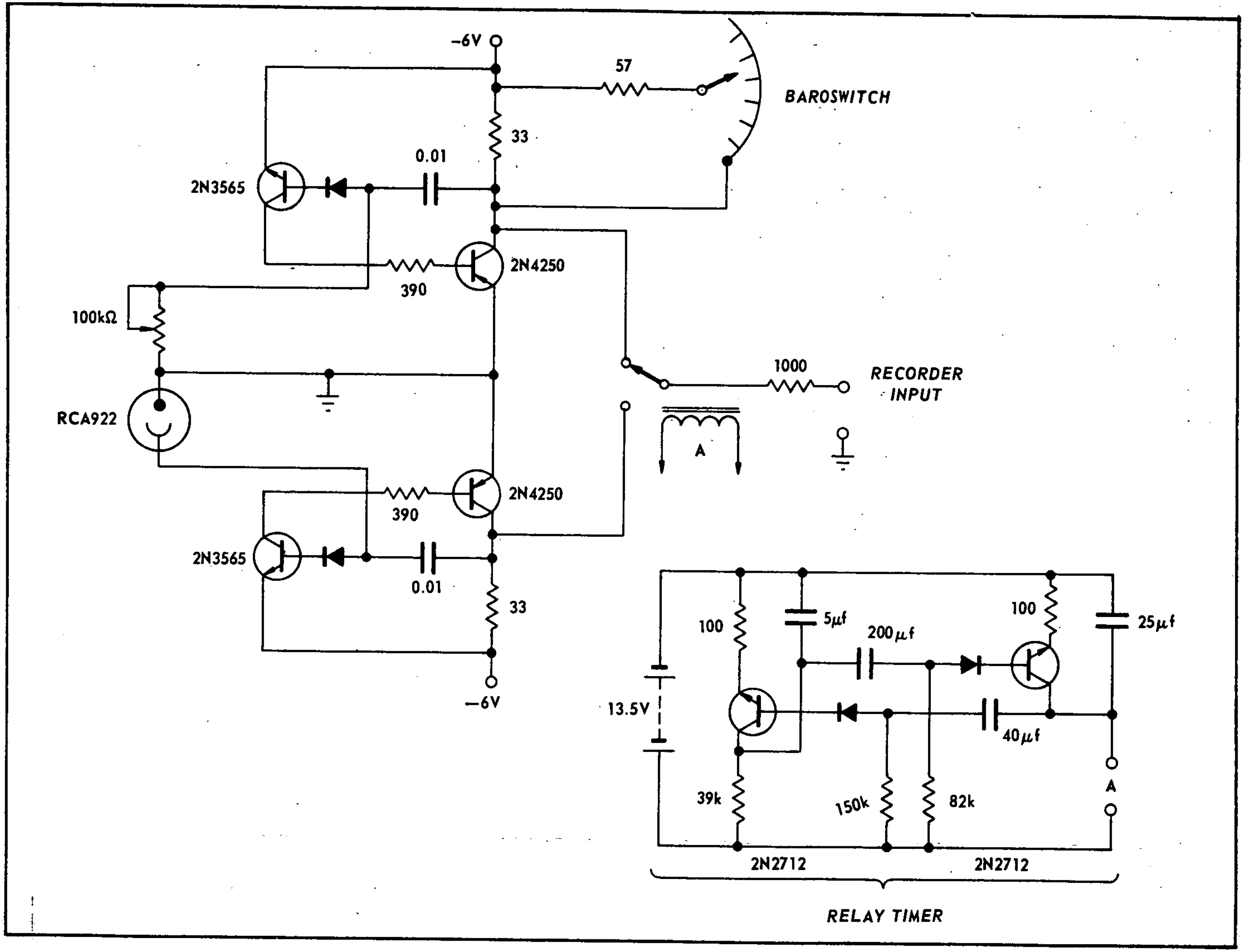

Figure 1. Circuit diagram of instrumentation.

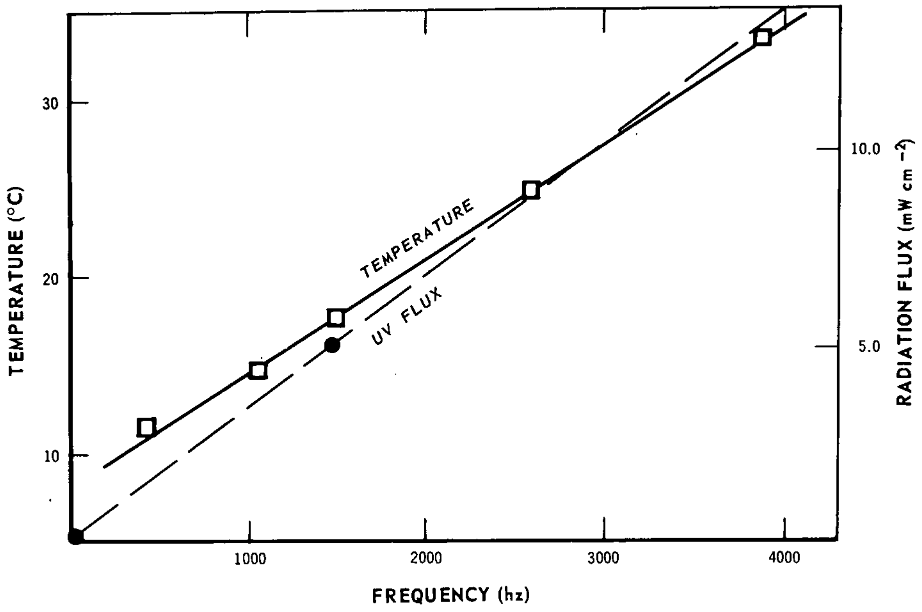

Figure 2. Calibration of the sensors. "Calibration" of the UV sensor was made at one point only simply by comparison with the normal UV record at Aspendale. Linearity was checked to be within 4 per cent by tests under a calibrated Tungsten lamp with the UV filter removed from the sensor.

The largest source of error arises from variation in tape speed with battery voltage (*ie*,with time), and because of this the replay of a tape was always conducted with batteries of the same usage history as that of the batteries during flight. By this means the accuracy of frequency reproduction can be kept to better than 2%.

Vibration from the aircraft motor is considerable, and some care had to be exercised to shock-mount the thermistor (which is subject to breakage) and the baro-switch (whose wiper arm tends to chatter on the contacts). The baro-switch was completely suspended by rubber bands inside the fuselage. The tape recorder and electronics are vibration proof, but all battery and lead connections had to be solidly clamped.

THE AIRCRAFT

The model was manufactured specially for the purpose (Fig 3). It weighs 3 kg, has a shoulder-mounted wing for stability (2.5 m span), and is powered by a 10 cc 2-stroke glow ignition motor. The motor is inverted, so that exhaust gases and fuel spray are expelled below the aircraft (*ie*, not over the radiation detector). The radio control is a "full-house" digital proportional system (*ie*, with all flying surfaces controllable and trimmable) operating on 27 Mhz. Fully loaded with 500 gm of fuel, the model requires about 30 m of fairly smooth ground for take-off or landing in calm conditions, with about three times that distance clear of obstacles such as trees and houses. It can be taken-off safely in surface winds gusting to 20 kt. In more adverse conditions of restricted take-off area or of high wind gusts and the model can be hand-launched from a vehicle. In calm conditions the maximum rate of climb or descent is about 3 to 4 ms^{-1}.

The operator must be able to see the model to control it. This sets an upper limit to altitude (when controlled from the ground) of about 1.5 km on a clear day and a little higher for overcast conditions. Range can be increased somewhat

Fig 3. The model aircraft. For actual trials the motor was inverted. The electronics and tape recorder are mounted just behind and beneath the motor

using field glasses, but the procedure is dangerous since once lost from the field of view the model is very hard to pick up. At 1.5 km the motor is barely audible and is of little use in location. The technique used in the present trials was for the operator to keep the model in sight visually unaided, with a second person equipped with wide-angle (11^{o}) field glasses instructing the operator on aircraft attitude.

In early trials both spaced theodolites and an optical range-finder were used in an attempt to check altitude, but neither technique was successful because of location problems.

FLIGHT RESULTS

Figure 4 is an example of a raw record played back onto chart. This record was one from a series of flights conducted during two days at Rutherglen in northern Victoria, and was obtained in clear sky conditions. During both ascent and descent the aircraft was set at a constant trim so that it would climb or descend at a uniform speed while executing a uniform spiral about 500 m across. Banking was minimized.

The results are not plotted formally, but appropriate temperature and UV radiation scales are put at the beginning and end of the record. The temperature trace shows a significant inversion close to the ground, and the descent profile reproduces that of the ascent to a precision of 0.5°C. Note that the motor was switched off during descent, which indicates that its operation does not interfere with the recording. The altitude marks (the regular displacements of the temperature trace to the right) are adequate for single profile measurements, but for flights involving various altitude changes other than a single ascent the individual markers would need to be differentiated. This is possible with the radiosonde baro-switch which can be wired to give three classes of contacts each with a separate displacement, and this would simplify identification of particular contacts.

The UV record displays no significant height variation. However, "significant" here means a change of greater than (roughly) 10%, as random attitude changes of the aircraft introduce noise on the record. This noise increases with altitude and can be, as here, up to 25% of the mean signal level. It is notable that a conscious effort on the part of the operator to minimize attitude changes does not improve the signal, and in any event he cannot see the aircraft sufficiently well at the higher altitudes to attempt correction. In order to achieve greater accuracy in the measurement of global radiation fluxes, it is necessary to maintain the aircraft at a fixed altitude for some time in order to average the results.

Very little comparative information is available on the expected change of UV flux with altitude. It is known (*eg*, Koller, 1952) that the *direct* UV intensity increases with altitude since the radiation does not traverse as thick a layer of atmosphere at higher altitudes and the scatter and absorption is less. On the other hand the scattered UV component (which can comprise a major portion of the total at lower solar elevations) decreases with altitude. The net result would be an expected increase with height of the total global flux, accentuated in atmospheres of high turbidity. As an example of possible orders of magnitude, for unspecified conditions and wavelength Koller quotes an increase of 15% per km in the global flux of UV in the Alps.

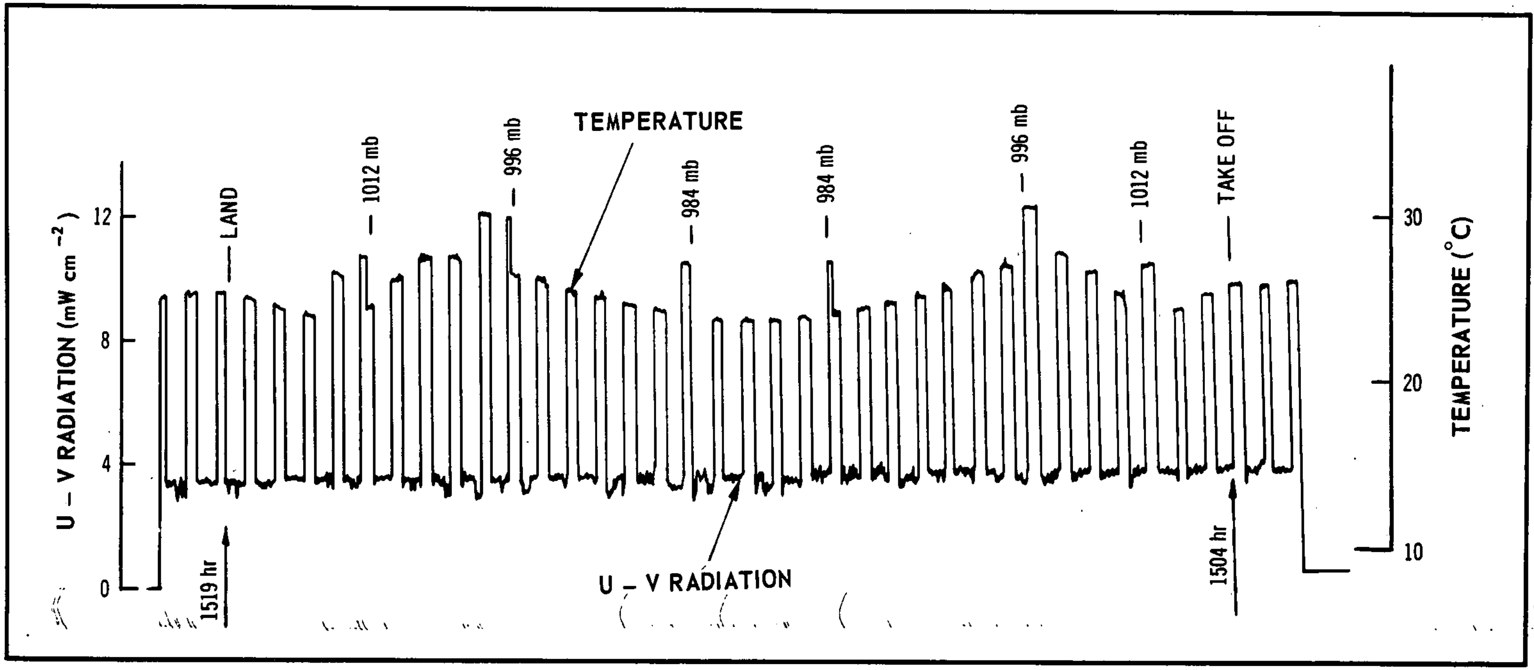

Figure 4. Chart replay of actual record from clear-sky flight at Rutherglen.

Bearing in mind the accuracy of the measurements, the lack of height variation of UV is perhaps not surprising at Rutherglen as the atmosphere there is remarkably clean as compared to that of urban areas in general. However, several flights of various types have been conducted in and near urban Melbourne on cloud-free days, and on none of these occasions has any significant variation of UV with height been observed. One such occasion was a flight to 1 km in the centre of the major industrial area of South Melbourne, in the early afternoon of a day on which restriction of visibility by atmospheric pollution from local industry was said to be unusually great. There was a slight inversion at 0. 8 km, the height of cloud tops earlier in the day, and one would have expected clearer air above it. These negative results are at variance with those of Stair and Nader (1967) for instance, and with what would be expected from the work of Galbally (1971). However, the data available from the flights to date are too few and too inaccurate to make any definitive statement.

CONCLUSIONS

The technique has a number of applications. It is particularly suitable for measurements of scalar quantities where rapid and repeated profiles are required A complete ascent to 1. 5 km and descent can generally be accomplished in less than 20 min, although on days of high thermal activity quick descents can prove difficult even with the motor switched off at the top of the climb. Turn around time on the ground can easily be kept to less than 5 min. The aircraft is not greatly affected by weather and can be flown at any wind speed up to its own maximum air-speed of about 45 kt. It can, however, be lost easily in cloud. Though such experiment have not yet been tried, the technique would be extremely valuable for measuremen in and around smoke and thermal plumes, where rapid and accurate placement of sensors is required. The airspeed of the present aircraft can be kept as low as about 10 kt.

The instrumentation described here is rather simple and can be improved in several directions for specific experiments. The model can carry almost double its present load with some sacrifice in performance, or could be re-designed for a higher load-carrying capacity. (It could also be re-designed for specific performance characteristics such as higher speed, lower stalling speed or faster rate of climb, *etc*). The stability, accuracy and sensitivity of electronics can be improved readily. In particular, the effect of variation in tape speed could be eliminated by occasionally switching the tape input to a reference frequency - perhaps via the baro-switch.

It is worth mentioning that in the interests of safety (for the model) an experienced "pilot" is essential. The cost of the present aircraft (apart from the instrumentation) is roughly $800.

ACKNOWLEDGEMENTS

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