A sensitive instrument for measuring the temperature gradient in convective air from a sailplane

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Introduction

The common method for the glider pilot to acquire definite information about the location and magnitude of rising air currents is to take recourse to a trial-and-error method and to observe the variometer. The direct correlation between the vertical velocity of the air and its excess temperature over the environment in convection currents, i.e. thermals, makes it particularly attractive to consider technical means of gaining information about such upcurrents from a distance. Various long wave infrared radiation techniques can be proposed but they are susceptible to gross interference by radiation from the sun, earth and clouds. Besides, infrared systems are not very suitable for sailplanes, for instance the cost is inclined to be high.

Temperature Gradient Measurement

Another, although inherently a more restricted method of obtaining useful information about the position of thermals in relation to the glider, would be to measure the temperature difference in the air between the wing tips. The relatively large wingspan and slow airspeed of a sailplane are great advantages in making the measurement practical. To gain insight into the possibilities and limitations of this method it is useful to some extent to review the physics of thermal transfer.

Vertical convection has been studied by direct measurements in practice, by model experiments in the laboratory, as well as in theory. Some recent interesting work is reported in references 1 and 2. Warm, buoyant air rises in form of plumes, bursts or bubbles, that spread and cool as they gain height. In practice there is generally a turbulent boundary layer near the ground up to about 100–300 meters' height but above this level convection is usually well-formed and concentrates on relatively narrow areas. Typical diameters of a thermal range from 100 m to about 400 m. If an axially symmetric convective plume is considered, there is evidence that a Gaussian curve would fit reasonably well to the profiles of both the vertical velocity and the excess temperature of the air (fig. 1).

The sailplane pilot notices the hitting of a thermal from increased turbulence, momentarily raising airspeed and from the variometer. If he wishes to gain height, he starts a steep thermal turn but it is often difficult to decide which direction to choose. The more nonradially the entry takes place the more important it is to start turning into a specific direction (refer to fig. 1). If it is possible to measure the horizontal temperature gradient with minimal delay, the right decision can be made.

When circling in a thermal it is common practice to strive for a steady rate of climb. In the ideal plume this means a concentric circle and the temperature difference between the wing tips would be constant, with the warmer air inside. However, it is not a simple matter to correct nonconcentric circles with the temperature difference meter. This can be conceived by imagining various circling paths in fig. 1. The temperature gradient may behave quite similarly in entirely different circling positions and to avoid ambiguity recourse to the variometer is necessary. It is obvious that in practice the best thermal circle is attained most efficiently using only the variometer, especially when a total energy instrument is at one's disposal.

In order to get a concept of the desired detectivity of a temperature gradient indicator on the wingtips of a 15 m wing span glider approximate calculations were made based on various theories of convective transfer in meteorological literature. It was concluded that to be of use in normal thermals the instrument had at least to be capable of detecting temperature differences of 0,1° C. The time lag should naturally be small, but a few seconds might be

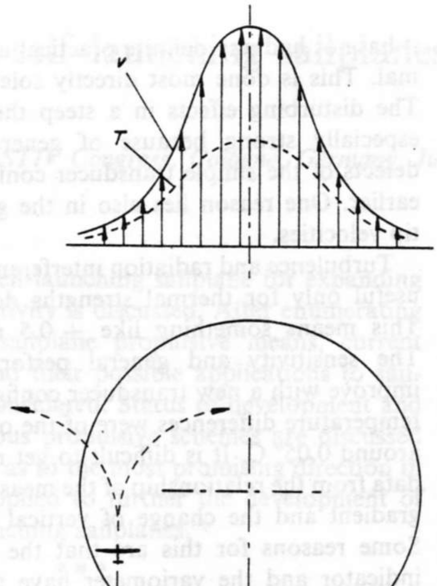


Fig. 1 Profiles of an axially symmetric convective plume. T = excess temperature of the air, v = vertical velocity

tolerated as in a variometer. Some time delay does not actually interfere much when a decision has to be made of the preferred turning direction on penetrating a thermal, as it is not usually advantageous to begin turning immediately (refer to fig. 1). Of course when the contact is only tangential action should be taken without delay.

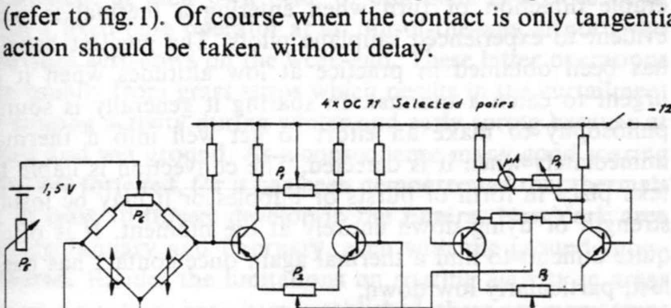


Fig. 2 The employed temperature difference measuring circuit

A Practical Instrument

An experimental temperature difference meter was constructed at the Laboratory of Technical Physics, Finland Institute of Technology. To make the instrument of practical value inspite of its inherent limitations emphasis has to be put on simplicity and low cost. It is of technical advantage that interest is focused only on a temperature differential on a qualitative basis. In addition, the instrument will be mainly used in practice to detect rapid changes or transients in the measured quantity.

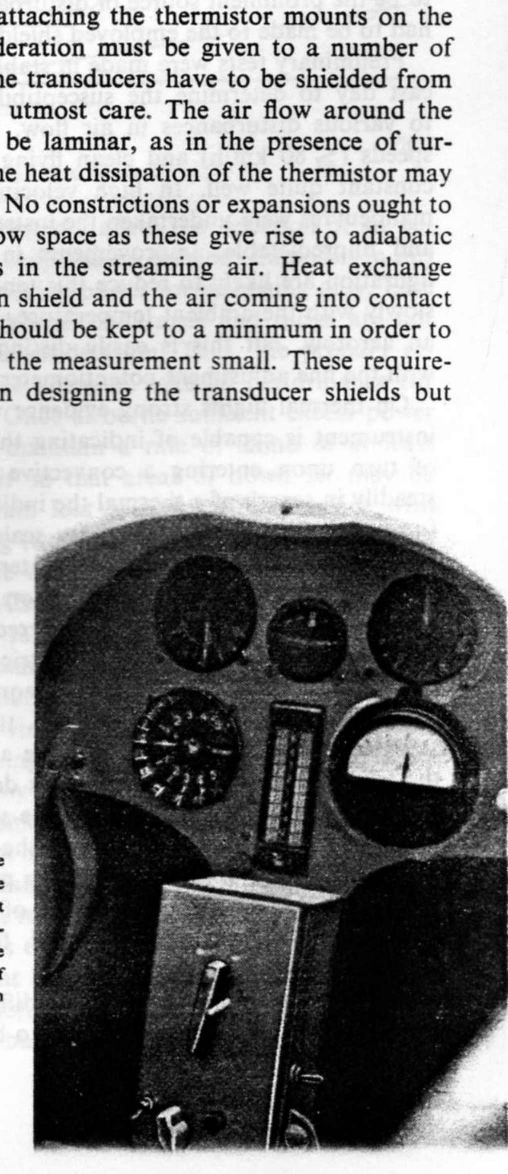
Thermistors are used as temperature transducers. The type suitable for this kind of temperature measurement is in which a miniature resistance bead is immersed in the tip of a thin walled glass tube. Small size, great sensitivity and adequate ruggedness are chief advantages of these transducers. Thermistors used in the experimental apparatus were of Standard Telephones and Cables type F 23. The examined samples seemed to possess sufficient physical and electrical homogeneity. These thermistors are also available in matched pairs. The manufacturer does not give information about the time constant and measurements were not undertaken but it is concluded that the lag will be about 1–3 seconds in the air velocities of interest. The electric current in these resistors has to be kept very small so that the power dissipation does not interfere with measurements.

The temperature difference is measured in a Wheatstone bridge, amplified in a two stage transistor differential amplifier and indicated on a centre-reading microammeter (fig. 2). Transistors are suitable in the amplifier because of their reliability, small size and low current and voltage needs. Their greatest defect, strong dependance of ambient temperature, is a source of difficulties in this particular application. The temperature is liable to change over a wide range and the signal to be amplified is extremely minute. In order to reduce the effects of ambient temperature on the amplifier a compensating feedback circuit is adapted, the transistor pairs have been selected and matched, and zero output has been adjusted at two temperatures with the first stage potentiometers P_1 and P_2. To minimize the effects of temperature transients and draft the amplifier is enclosed in a plastic foam case and the transistor pairs are mounted on a common copper heat sink. The remaining temperature drift is corrected with fine zero potentiometer P_3. The sensitivities of the bridge and the microammeter can be adjusted independently in the experimental instrument.

The amplifier takes only 4 mA from a 12 V dry cell. The detectivity for transients in the input is about 0,5 nA (= noise level). In the measurements input currents of the order of 5–50 nA corresponded to temperature differences of 0,01 to 0,1° C. The amplifier has operated satisfactorily in the ambient temperature range of 8–25° C.

In designing and attaching the thermistor mounts on the wing tips due consideration must be given to a number of things. First of all the transducers have to be shielded from solar radiation with utmost care. The air flow around the thermistor tip must be laminar, as in the presence of turbulent fluctuations the heat dissipation of the thermistor may be seriously affected. No constrictions or expansions ought to be allowed in the flow space as these give rise to adiabatic temperature changes in the streaming air. Heat exchange between the radiation shield and the air coming into contact with the thermistor should be kept to a minimum in order to keep the time lag of the measurement small. These requirements can be met in designing the transducer shields but

The instrument panel with the experimental apparatus. The centre-reading μA-meter is at right in the lower row; Cosim-variometer is in the center. The amplifier is below in front of the stick. Compass & oxygen meters were removed



The test plane, PIK-3c, a standard class glider designed in our club. (Prototype placed 4th in Leszno. About 15 have been built.) The temperature transducer is visible on the tip of the wing

the simple experimental configuration had defects in some respects. In addition, the location of the transducer mount is important. For the tests thermistors were mounted on the blunt wing tips of a PIK-3c. This seems not to be the optimum solution as in the slightest slip there is bound to be gross assymmetry in the air flow in the measuring space.

Flight Experience

Flight tests have been carried out into late autumn in a PIK-3c in the Flying Club of the Institute of Technology. It was found to be best practice to keep the measuring bridge switched on only in the air as there are always such temperature gradients and microconvection near the ground that cause the amplifier to saturate and also the microammeter to require a special coarse scale. Solar radiation turned out to be the prominent source of disturbance and modifications had to be made to the employed shields to reduce the effects.

Preliminary tests were made in stable weather on an overcast day to determine the susceptibility of the instrument to various disturbances in air flow. At relatively low airspeeds (≦ 80 km/h) and clean flying the output remained constant quite well. In high velocities and when violent manoeuvres were undertaken the instrument turned unstable and unpredictable. Improvements in the transducer configuration are likely to reduce this tendency. The zero drifts slowly with the ambient temperature, as for instance during an aerotow, but this is easily distinguished and corrected with the fine adjustment potentiometer.

On thermal flights strong evidence was obtained that the instrument is capable of indicating the preferable direction of turn upon entering a convective area. When cruising steadily in search of a thermal the indicator stays fairly calm (on a certain range of sensitivity scales) drifting perhaps a little to the side of the sun. On entering a thermal the instrument usually reacts very clearly on the appropriate scale. This indicates that there is a preferred direction of turn or in other words an axially symmetric plume or bubble is penetrated nonradially (in ideal theory). When the turn is begun according to the instrument, the variometer usually stays constant or rises. If it is done against the indication, the variometer nearly always shows decreasing lift. Success cannot be expected every single time since thermals are not always well-formed. The gradient of the thermals encountered during the test flights were never so pronounced or free of turbulence that a distinct indication of the preferred turning direction could have been obtained, for example from the tipping of a wing.

When circling in a thermal the difference meter usually indicates the air inside of the circle to be warmer, but so far it has not had any definite practical use in centering in a thermal. This is done most directly solely with the variometer. The disturbing effects in a steep thermal circle tend to be especially strong because of general turbulence and the defects of the simple transducer configuration as mentioned earlier. One reason lies also in the great difference of wing tip velocities.

Turbulence and radiation interference made the instrument useful only for thermal strengths down to about 1,5 m/s. This means something like + 0,5 m/s in the variometer. The sensitivity and general performance is expected to improve with a new transducer configuration. The measured temperature differences were of the order calculated, usually around 0,05° C. It is difficult to get meaningful quantitative data from the relationship of the measurement of temperature gradient and the change of vertical velocity upon turning. Some reasons for this are that the temperature difference indicator and the variometer have their own specific time constants, the sinking speed of a sailplane is a function of the turning radius, the radius is large in relation to the measured interval, i.e. the wing span, the structure of convection may vary, turbulence interferes, etc.

Discussion

The utility of an instrument capable of indicating the preferable direction of turn when entering a thermal is well evident to experienced sailplane pilots. The greatest benefit has been obtained in practice at low altitudes when it is urgent to catch a thermal. In soaring it generally is sound philosophy to make an effort to get well into a thermal immediately when it is detected. The convection is liable to take place in form of bursts or bubbles or it may be losing strength or dying down entirely at the moment. It is often quite difficult to find a thermal again once contact has been lost, particularly low down.

Final conclusions of the value of the instrument can be drawn only after an extensive period of tests carried out in different conditions and by different individuals. Disturbing effects should be eliminated and the detectivity improved. Progress in this direction is anticipated in the future with another transducer configuration. Also investigation and minimization of the time delay ought to be undertaken. In addition the installation of the amplifier with its adjusting knobs in the crowded cockpit of a high-performance sailplane should be carried out with more consideration than in the experimental effort. The Flying Club of the Institute of Technology, Helsinki, continues to carry on work along these lines.

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