A Thermistor Thermal-Detector System

By R. L. Schellenbaum

In the modern sailplane, the tendency is to use more and more sophisticated instruments to enable the pilot to secure the maximum possible performance. Few papers on such instruments have appeared in these pages, and the following paper dealing with an electronic thermal-detection device is reprinted from 'Soaring', the journal of the Soaring Society of America, issue of February 1968.

*

Practical thermal detectors as aids to soaring have been considered for many years. Reports of results have been few and difficult to locate, in my experience, and rather pessimistic regarding temperature methods. The purpose of this paper is to report the results of recent observations of a thermal-detection system using thermistor temperature sensing methods, as employed in a Schweizer 2-22E of the Albuquerque Soaring Club. This report is preliminary in nature because of the limited availability of the 2-22. But the system is felt proven in operation, at least qualitatively, and appears quite useful. However, the success and value of the detector is left to the opinion of the readers, some of whom may be interested in further development and testing. The application of this device can possibly be extended by the discerning operation and interpretation of pilots more experienced than the writer. Testing here awaits the completion of a Cherokee RM.

Background

This detector grew from the application, over a long period, of a thermistor device to free-flight model airplanes as published by Bruce E. Packham. The results in the field were impressive. In basic operation, the output meter displays the *rate-of-change* of temperature at a point in space as the thermal passes over the ground station, i.e. a temperature variometer indicating both red and green air. The thermistor is mounted on a pole eight feet above the ground and is shaded from the sun. A foot square, light, silk flag is mounted horizontally on a wind-direction vane just below the detector and is, in itself, a good thermal indicator, serving as verification. Output signals were easily interpretable in terms of the usual thermal temperature profile. The amplitude and time duration of the meter deflection, taken together, indicate proportionately the thermal strength, profile, and, along with the wind velocity, the size of the thermal-detector intersection. With experience, one is able to 'calibrate' the meter deflection in terms of thermal strength with reference to the model. For example, a deflection of about onefifth scale for two to three seconds in a light breeze is fair lift for a Wakefield rubber model having a sink rate of approximately 1.2 ft./sec. One-half scale for three seconds is strong lift and, substantiated by the silk flag, will insure long thermal flights with practically 100% reliability. Anything larger is a boomer.

Application to Soaring

The main objectives considered for soaring were (1) to detect non-visible thermals at a distance, (2) to determine the proper direction of turn upon encountering a thermal if not otherwise obvious, and (3) to more easily and accurately center the thermal for efficiency. To these purposes, it was concluded that the best detector configuration should consist of a temperature rate sensor (TRS), as described above, at the nose of the plane and another device with sensors at each wing tip displaying the temperature differential (TDS) across the wings—the usual arrangement. This is the system tested so far.

This system is dependent entirely upon the measurement of temperature variations and will not operate as intended in water-vapor lift, although the possibility exists with modifications and/or re-interpretation. Also, dynamic cooling from different tip speeds in a turn and different wing-tip elevations in the bank will induce TDS signals towards the turn center and will obscure the thermal-centering function of the detector if the free-air temperature gradient is typically 1°/100 meters and the horizontal thermal gradient is 5°/1000 meters, as stated in reference 1. It should be mentioned at this point that the results of these effects have been observed and make the TDS function ineffective in a banked turn. However, objectives (1) and (2) above can still be met and may be the most valuable. The TRS signals should be unaffected in a turn, although dynamic cooling could induce false indications in the same manner as 'stick thermals'.

It is important that the operation of the TRS be well understood in the following discussion and for correct interpretation of the TRS detector meter deflections. Remember that this shows a *rate-of-change*, not true, absolute temperature. If a positive temperature is applied (entering a thermal) at the thermistor in the shape of a nearly square wave with respect to time, the meter needle will show a positive deflection during the sharp rise in temperature only and will return to zero during the constant-temperature flat top of the wave (because the rate-of-change is zero). When the temperature source is quickly removed (leaving a thermal), the meter will deflect negatively (from zero) because the thermistor rate-of-change is now negative in cooling back to the original constant temperature, whereupon the meter returns again to zero. A differential detector of this sort picks out sharper and continuous changes from the lower background variations, depending upon the electronic time response and sensitivity. The output signal must be mentally integrated, as used here, to give the absolute temperature profile of the thermal. The signal directions above will be inverted when a region of cold air is entered rather than a thermal. In the following, the relatively quick deflection return to zero is not explicitly noted in the descriptions.

Idealized operation of the system is briefly as follows. A simple thermal model is assumed to consist of a rising bubble or column of warmer air expanding adiabatically, with a possible significantly warmer center or 'core'; turbulent mixing on the periphery; and a tail, or temperature gradient, extending radially outward into the ambient air. (1) Flying *by* a thermal would produce a TDS signal in passing through the tail beyond the turbulent mixing region which is essentially the thermal boundary. The detection distance of the thermal proper is a function of the magnitude of the tail temperature gradient and the detector sensitivity. The TRS signal should be very small, depending upon the same factors, since the plane is traveling at nearly right angles to the radial temperature gradients. After turning towards the indicated thermal, (2) or (3) will apply. (2) Approaching the thermal head-on and traveling through the center, the TRS would indicate the entire profile with no signal from the TDS, which has decreased to zero during the turn. (3) Approaching head-on, but off-center, would produce the same type TRS signal as (2), but with a TDS indication of a warmer core, if significant, and only for very low angles of bank. (4) It appears that the TDS detector is eliminated for centering purposes once inside the thermal. It is conceivable that a very sensitive TRS detector may be used to center by flying a null signal at the smallest possible turn radius. This is believed beyond the capability of the present TRS.

Results and Observations

The instrument box was mounted under the 2-22 panel, using existing name-plate screws. The TDS sensor heads were mounted on the inboard sides of the wingtip skids. The TRS head was positioned well back on the pilot tube.

A total of only 15 test flights have been made at this time. However, the observed signals have been consistent and interpretable, as in the model application, and cross-check well with subsequent pellet-variometer indications, giving a high degree of confidence in their validity. Many of the flights were made dual, and observations were confirmed by Herman Wente of the ASC, an experienced flier. Our 15-year-old member, Jeff Miriam, also reported locating lift with the unit.

The test and evaluation may best be presented by describing typical observations from a few inclusive flights and on tow.

1. The detectors were first zeroed in the hangar to avoid turbulence. This was found unnecessary, as it can be done on tow or later during steady periods in the air. Glancing at the detectors while on tow is instructive, with the towplane acting as another probe about 200 ft. ahead. Off-scale TRS deflections are occasionally seen in rougher conditions. Signals are generally seen on the TRS on or slightly before the towplane rises upon striking lift and before either the glider or pellet reacts. Thus, the effective TRS detector range appears to be at least 200 ft., or 2.3 seconds at 60 mph, and is dependent upon the temperature gradient, airspeed, and detector sensitivity. This suggests another operational factor. Because the effective TRS sensitivity increases with increasing airspeed along a given temperature gradient, the range will increase also, but the closing time between the plane and the main thermal body should tend to remain constant (two to three seconds?) with airspeed. This effect should be most true when the TRS is in the far temperature profile tail, where the gradient is fairly linear, and is limited by the lower threshold of signal detection.

2. On the first flight at 8:30 in the morning, a onefifth scale TRS signal was observed an estimated two seconds before feeling slight turbulence. Altitude was maintained for a few minutes by circling. No indications were observed from the pellet variometer or TDS. (A few short, early morning flights were also made later in stable air, during which all instruments read a nearly rock steady zero.)

3. On the second flight and a number of others, the TDS indicated about one-fifth scale (both right and left), and weak turbulence was encountered after a shallow turn for three-four seconds at 45 mph to about 90 degrees. This gives a detection distance of roughly 150 ft. A fairly steady, one-fourth scale TDS signal towards the circle center was seen. Sharp TRS signals occurred only during the turbulence. No pellet action was observed. It should be emphasized that small, short signals on one or two of the three instruments may be missed, especially at first and while engaged with flying. TRS signals are typically short because of the detector differentiation. However, pellet action is quite noticeable and was generally given special attention for checking purposes.

4. Most of the remaining information can be given as observed during a particular flight to 12,000 ft. as in stronger thermal conditions. Four thermals were used, and more time was available for testing. Unfortunately, at this time the TRS thermistor was replaced with one of the type used in the TDS with a faster response time in an attempt to obtain greater TRS signals when turning towards a thermal. The resultant response with unchanged electronic differentiation produced erratic TRS signals on tow and later, which did not correspond well with pellet readings, so TRS information was essentially lost. The response appeared to follow short turbulence pulses and, in one instance, gave a strong negative signal while the pellet and altimeter indicated good lift. Correct values of thermistor response and electronic differentiation must be attained for proper operation. The original thermistor will be replaced and sensitivity increased by other means, although the TRS signal when turning towards a thermal is probably inherently low because of the usual slow turn.

Release was made in lift, taken for a couple of thousand feet gain, and ended in a region of steady zero readings. In heading for a cloud, a TDS indication to the right was noted, a turn made, and turbulence and lift contacted after four-five seconds. The range here appeared to be greater, about 300 ft., as might be expected under stronger lift conditions (generally no more than half scale on the pellet). In circling to thermal, a three-quarter scale, steady, TDS deflection towards the bank was seen for a few turns. As a test, the wings were brought level while still indicating lift by the pellet and altimeter. The TDS needle swung back to zero, following nicely the reduction in bank. Later, in stable air, banks in either direction produced the same results with a seemingly reduced magnitude of about half scale, assuming equal bank angles. Also, on a previous flight only a small TDS signal was observed during a fairly steep slip, which (together with the above) says that the obscuring TDS signal during a banked turn in thermaling is for the most part the result of dynamic cooling.

A straight fly-through with wings level was made. Only turbulence was felt on entry and exit, and lift but no significant TDS signals occurred to suggest a warmer core.

Losing this lift and traveling along in stable air, a TDS signal of about one-fifth scale to the left was seen, and turbulence and lift found after a turn of about 90 degrees in an estimated three-four seconds. In thermaling to about 10,500 ft., the only anomalous indication observed occurred. The TDS indicated warmer air to the left while in a fairly steep bank to the right *for about a full turn* with green air indicated. The wings were leveled to check some slight turbulence felt which may have been a stall warning in this case, and the lift was lost. The TDS detector then came to zero and subsequently functioned quite normally. This is believed to be a real signal produced by the internal structure of the thermal and was probably encountered in a position near the turbulent mixing boundary. It may be concluded that the upper wing tip was in a layer of warmer air. There are, no doubt, a great variety of thermal characteristics encountered in soaring, and it would seem that instrumentation of this sort can add detail and a better understanding of thermal conditions or at least add confidence in one's mental picture by confirmation.

Continuing, a heading was then made directly toward and about 1500 ft. under a relatively small cumulus, back toward the field. Approaching, the TDS insistently pointed to lift to the left of the cloud; the ship was eased over in that direction, and good widespread lift was found to cloud base.

Remarks

In summary, the TDS detector may be evaluated as increasing the effective wingspan and pilot 'feel' for lift by as much as 500 ft. The present TDS system appears to be of no value so far in centering. The practicability of displaying the difference across the wing of temperature rate-of-change signals, incorporated with the same thermistor sensor heads, is being considered.

The present TRS detector range is about 200 ft.

More experience and data are certainly required. Sensitivity increases are obviously desired. It is felt that coincidence has been ruled out by the results so far; although, the writer has as yet been too greedy to fly by indicated lift for experimental purposes, for example. In one instance, a turn was made on an indefinite TDS signal of about one-tenth scale above a slowly fluctuating background of one-tenth scale in an unsuccessful attempt to find the lift. It is significant that lift was found without fail on all other attempts. In these, a definitely observable, persistent, TDS signal of about one-fifth scale was noted above a slow one-tenth to one-fifth background.

Description of Detector

The detector unit is packaged in a 6¼ by 3½ by 2-inch aluminium box. The meters were found surplus and display the TRS signal (up or down air) at the left and the TDS signal (right or left) at the right. Zero-adjust knobs are below each meter. The on-off switch is at the bottom center. A sensitivity selector was installed at the top center, which simply switches a resistor across the TRS meter to reduce the deflection by a factor of two. This can be omitted at present because off-scale deflections are infrequent and too brief for switching. Sensor head connections are made on the Jones plug at the case bottom. The unit weight is 30 ounces.

The sensor heads were constructed of phenolic tubing and disc end plugs. The bead thermistor was soldered to an end of the plastic-covered speaker-wire leads and inserted into a $^{5}/_{16}$-in. diameter tube, with the bead extending about a quarter inch out the end. Silastic (rubberlike) bathtub caulk was used around the bead leads and into the tube to support the bead. The caulk was formed into a cone with the bead at the apex, keeping the bead clean. The leads were then rigidly epoxied at the other end of the tube. The thermistor cover is a ¾-in. I. D. tube with a ⅛-in. thick front plug and a ½-in. thick rear plug which is cone shaped, with the point facing forward. The rear plug is drilled for a tight slip fit around the bead-mount tube. A large number of $^{1}/_{32}$-in. holes were drilled in the front plate and in the surface of the lower half of the cover tube. Larger holes were drilled around the rear perimeter to allow free air flow through the tube and over the thermistor. The end plates were epoxied in place, and the thermistor tube inserted to center the bead in the cover. Electronic, plastic, cable clamps and screws were used to mount the heads to the wingtip skids.

The basic electronics of the TDS circuit diagram were stolen from the TRS detector of ref. 2 and were modified for this application. No additional effort was made towards improvement, because the sensitivity and signal to electronic noise ratio seemed about adequate as tested on the ground. Both meters are —50 to zero to +50 microamp movements, and the power supply (the cylindrical form in the case) is a stack of five 450-ma.-hr. Nicad button cells, which will operate the unit continuously for about 48 hours. On the bench, small signals due to turbulence can be observed with the thermistors separated a small fraction of an inch apart. A steady zero was obtained when the thermistors were held in direct contact, demonstrating what was taken as sufficient sensitivity for testing. No absolute calibrations have as yet been undertaken. The circuitry is changed to produce the TRS detector. Additional circuit changes are also listed. TH_2 is now the single TRS mounted at the sailplane's nose.

Sensitivity and operational improvements may be made in both circuits by using matched transistor pairs (Q_1 and Q_2) larger meter faces, and, possibly, precision components. Thermistor characteristics and electronic input circuitry can also probably be optimized.

References

1. 'Improving Thermal Soaring Flight Techniques', Dr. P. B. MacCready, Jr., *Soaring*, Dec., 1961.
2. 'The All Important Thermal', B. E. Packham, *Model Airplane News*, May, 1966.