INSTRUMENTS AND TECHNIQUES FOR LOCATING AND EXPLOITING THERMALS

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ABSTRACT

A prior study surveyed methods for locating thermals remotely, and for assessing thermal characteristics when flying near or in them so as to permit full exploitation of the thermals. The present study examines further the devices which now, with present technology, seem to be most practical.

For locating thermals from a distance, use is made of the fact that some thermals carry space charge aloft from the surface. This superimposes a horizontal potential gradient on the normal vertical fair-weather field, and it is possible that the horizontal field can be measured at a sailplane several kilometers away. Suitable instrumentation is discussed.

There are several techniques which should be capable of showing which way to turn from the edge of a thermal toward its center. All involve devices showing the lateral variation of some variable. Practical contenders are versions of the aforementioned potential gradient device, and a system showing the gradient of wet bulb temperature between the wing tips.

The strength of a thermal along the flight path is derived from a rate-of-climb indicator. Compensation methods are discussed for making this indication more accurate.

The buoyancy of the thermal can help indicate whether the thermal is growing or decaying. Relative buoyancy can be given, to adequate accuracy, by an instrument combining temperature and altitude information.

Visualization of the thermal is facilitated by introducing markers (long-lasting bubbles, or smoke put into the tip vortex), or by particular cockpit displays of vertical velocity which aid the human memory.

INTRODUCTION

This article is a sequel to a paper "Improving Thermal Soaring Flight Techniques" (MacCready, 1961). That paper noted the various characteristics of thermals which might conceivably be useful in assessing or locating the thermals, and then examined various techniques and devices which took advantage of these characteristics for aiding the soaring pilot. The present paper does not present any method which was not covered in the earlier article. The goal now is to select and discuss those few techniques which, because of improved instrumentation technology, might be especially easy and practical to apply.

The amount of money and effort devoted to improved instruments and flight techniques is probably still less than one percent of the amount which has gone into "improving the breed" of sailplanes. This tiny percentage deserves to be increased, especially because a small increase can be expected to result in significant improvements in soaring. As noted in the earlier article, "Perhaps it is really not surprising (...that structures and aerodynamic improvements receive so much more attention than do instrument and flight technique improvements), for aerodynamics and structures constitute scientific fields in which accurate calculations can be made, while the subject of 'thermals' is a vague thing based at present on incomplete physical understanding and is a field in which accurate equations cannot apply to a specific case."

LOCATING THERMALS FROM A DISTANCE

Of the various conceivable methods of remotely detecting a thermal on a cloudless day, covering passive and active devices using electromagnetic radiation, only one seems to have a chance of being really practical. That one is the use of potential gradient equipment for remotely sensing the net space charge associated with some thermals. To the best of my knowledge this has not yet been tried. It may not work, for many reasons. However, if it does work, at least sometimes, it will be practical because the instrumentation can eventually be rather simple.

There tends to be a weak net space charge in the air near the ground, the very air out of which a thermal builds its substance. Thus a thermal may have a net charge of between 1 and 1000 elementary charges per cubic centimeter. By conductivity, half of the charge will leak off in about 20 minutes near sea level (in just a few minutes at 3000 meters), so the charges from "old" thermals slowly disappear and will not tend to obscure the newer, more vigorous ones.

There is a normal vertical fair-weather field or potential gradient of about 1/3 to 1 volt/cm. The space charge of a thermal will superimpose some horizontal potential gradient, which should be detectable from a distance and could guide the pilot to the thermal. To find the magnitude of the effect, assume 100 elementary charges per cubic cm exist in a cubic kilometer of air. The total charge Q is then 0.016 coulombs. The field F from this is

$$F = - \frac{Q}{4\pi\epsilon r^2}$$

where r denotes distance from the charge center and $\epsilon = 8.85 \cdot 10^{-12}$ farad meter^{-1}. Ignoring image charges, this means 0.40 volt/cm at r = 2 km, which is a rather strong gradient which should be easy to measure. For the sailplane and the charge center both at 1-km altitude, the image charge reduces the net horizontal gradient from 0.40 volt/cm to 0.26 volt/cm. The actual typical space charge is not known. Chalmers (1967) reviews the observations of many investigators and shows that net charges of the order of several hundred elementary charges per cubic cm are common near the surface. Based on the above factors, one can say that horizontal gradients of the order of 0.1 volt/cm may be anticipated on some occasions several kilometers from a thermal.

To measure such a horizontal gradient, one can equip the sailplane with a field mill on each wing tip, measuring the lateral horizontal gradient at a point where the sailplane geometry causes the gradient to be strongly increased. The difference between the two observed gradients is a measure of the lateral horizontal field, while the sum is a measure of the charge on the sailplane itself. If one uses only a single sensor, it is not possible to distinguish between the sailplane charge and the environmental potential gradient. Since there is a vertical potential gradient in the atmosphere somewhat stronger than the horizontal gradient you are seeking, the wings should be kept close to level during the measurement. If a horizontal gradient exists, the sailplane will be pointing exactly toward (or away from) the space charge when the instrument shows a null. If all the charged thermals have the same sign, the pilot will know which way to turn when off null, and may get some information about thermal distance from the intensity of the signal.

The field mills could instead be on the nose and tail, looking forward and backward. The pilot would then hunt a maximum rather than a null, and the magnitude would more easily give a hint as to the thermal distance or strength. The sailplane does not vary much in pitch, even during turns, and so confusion with the coexisting vertical field would be minimized. Practical problems will be encountered in such an installation, the most severe being that the rear gradient unit will have spurious signals caused by configuration changes of the sailplane, i.e., tail control surface movements.

One could contemplate the use of a more exotic installation which, on crossed pointers, shows instantaneously the direction and magnitude of the field. The cylindrical field mill of Kasemir (1964) or the MRI Model 611 Cylindrical Field Mill, pointing down from the belly of the aircraft, can constitute the entire sensor system for this. The drag of this sensor configuration might negate the performance gains it could give, and its complexity is probably too great for sailplane use. The design concept behind the field mill is reviewed by Chalmers (1957). Mill units have existed for almost half a century. Modern solid-state technology makes the field mill very easy to build, especially the high impedance field effect transistor as the coupling to the conductor which is alternately shielded and unshielded.

Instrumentally, this thermal-hunting technique can be elegantly developed. The big questions are: (a) Is there really enough space charge associated with thermals to give appreciable horizontal gradients at a distance? and (b) Will there be too many horizontal gradients caused by things which are not thermals? Concerning (a), the answer probably is that on some occasions there will be adequate space charge, but not on all occasions. Concerning (b), the situation is very complex. Space charge accumulates at boundaries where the air conductivity changes, and the conductivity changes with aerosol concentration. The charge is often quite pronounced at an inversion layer and, since the inversion in convective situations may be bumpy rather than flat, horizontal gradients will result. Also, the normal fair-weather field will be non-vertical over non-flat terrain.

The only way to ascertain the effectiveness of the approach is to make field investigations, probably with existing sensors on powered aircraft. If the concept proves valid, the hardware for exploiting it for sailplane use can no doubt be developed, even for a plastic sailplane.

TURN DIRECTION INFORMATION

Once one is in a thermal, as verified by the rate-of-climb indicator, one is confronted with the question: "Which way to turn toward the thermal center?" The potential gradient system described above has an excellent chance of giving the answer. The distances involved are small, say 100 meters or so, and spurious effects of horizontal gradients from non-thermal sources should be relatively weak. The tip-mounted configuration is indicated here, but even a small double-probe at the nose should be sensitive enough. Since only relative information is needed, the mechanical shielding-unshielding of a normal field mill is not required, just insulated conductors with electronics with a rather long time constant (10 sec or more).

Another technique with a strong likelihood of success is the use of wet bulb temperature sensors at each wing tip. Use tiny, fast response thermistors in a simple bridge circuit indicating the temperature difference between the tips. Have a tiny wick affixed to each thermistor, so as to keep it moistened from an adjacent tiny water bottle. Such sensors used in meteorological studies have been made with time constants shorter than 0.1 sec. Here one second should be quite adequate. The center of a thermal will be moister than the environmental air, as is especially evident once cloud level is reached. Thermal sniffers which rely on the dry bulb temperature difference across the wing span have not proven to be satisfactory. The horizontal temperature gradient across a thermal is far too small, and the large vertical temperature gradient which also exists causes spurious indication when the sailplane is banked. Wet bulb temperature, on the other hand, has a strong gradient across a thermal, and no strong vertical gradient in convective situations, and so should work for locating cores. The wet bulb thermistor technique is very easy to implement.

BUOYANCY GROWTH MEASUREMENTS

The original article pointed out that a measure of thermal buoyancy could give a clue as to whether a thermal is accelerating or decelerating, and hence whether it would be expected to be stronger or weaker in a few minutes. The measurement involves noting the air density in the thermal in contrast to the air density in the surrounding environment. Since the sailplane will be changing height while going from the environment into the thermal, the instrument must make an altitude correction to the density observation. The direct measurement of density is awkward, and so the obvious technique to employ is to measure temperature. The altitude correction is about 1°C per 100 meters. The exact factor changes slightly with altitude and mean temperature, but a single value chosen for representative conditions will be found adequate. There is also a humidity effect--the higher humidity within a thermal adds to its buoyancy. This effect can be estimated as a function of altitude for the particular day, from knowledge of the temperature and moisture sounding, and used to tell what temperature difference (altitude corrected) is needed at a particular altitude to give neutral buoyancy. The problem with the buoyancy instrument is how to make it simply. With modern, high grade, electric variometers, it turns out altitude changes can be turned into a voltage by integrating the variometer output--a simple task with solid-state components. This voltage is added to the temperature voltage, with the correct scale factor. This yields buoyancy, if humidity effects are ignored. Obviously humidity can be sensed and electronically added to the computation, but as pointed out above this refinement is not necessary. The altitude-temperature sensing and mixing circuit would have a zeroing button so that prior to entering a thermal the two variables could simultaneously be set at "zero" and so stay on scale for the required length of time.

VERTICAL VELOCITY MEASUREMENTS

From the standpoint of a soaring pilot, the definition of a thermal is given by its vertical velocity. This is measured at the sailplane by noting the vertical velocity of the sailplane via a rate-of-climb indicator, plus by noting the vertical air motion relative to the sailplane (by "seat-of-the-pants" judgment, by the aid of a total energy device, etc.). Vertical velocity measurements can be made to an absolute accuracy of several cm/sec by sophisticated systems involving an inertial platform with accelerometers and gyros, and super-accurate air motion vanes, but this is unsuitable for sailplane use by factors of 100 or more in weight and cost.

The sailplane pilot relies basically on a fast-response rate-of-climb indicator. The largest error is corrected with a total energy attachment, but other significant errors remain. The regular sinking speed due to sailplane drag constitutes one main error, and horizontal gusts constitute the other. The sinking speed error can be partially handled by the method described by MacCready (1954) which generates a flow in the instrument which is a crude approximation of the sinking speed vs. forward speed relationship for the particular sailplane. Other electronic analog methods are also available. The correction is not accurate during maneuvers which alter the load on the sailplane, such as zooms and turns. Conceptually, this could be handled by integrating a "G" meter into the correction.

The horizontal gust problem is introduced by the total energy compensator. This compensator cannot distinguish between airspeed changes due to horizontal gusts and those due to horizontal accelerations of the vehicle--and the gust effect causes larger errors as the sailplane speed increases. The partial cure is to filter the compensator so as to damp the rapid gust effects. Conceptually, a horizontal accelerometer could be incorporated into the system, although the changing component of gravity along the accelerometer sensing axis causes complications.

To put the matter in perspective, it appears that the best compromise is to have a total energy variometer, and add the simplest form of drag corrector and damp the total energy attachment--and then put any further effort into developing techniques for presenting the data to the pilot and having the pilot use the data by the optimum flight maneuvers. In data presentation, the desirable feature is a memory aid so the pilot can recall the vertical velocities at all prior positions in the thermal. A time plot of upcurrent strength is of some help. A printout of an X-Y plan position indicator is even more helpful--but very complex.

After one considers various data display methods, it becomes obvious that a visual marker of the sailplane trail would be most helpful. Smoke or bubbles could be released from the sailplane to mark its trajectory. The smoke would be longest lasting if released from a wing tip where it will enter the somewhat protected tip vortex. The smoke would presumably be formed from an oil fog, from a tiny electrical vaporizer. The prior trail would show the pilot at a glance the thermal configuration. Perhaps it could even be able to suggest the thermal rotation, which is something which would be very complex by instrumentation alone.

CONCLUSIONS

The techniques discussed here are about half of those recommended for further attention in the article prepared a decade ago. The emphasis then was on what could realistically be done. The emphasis here is on what can be done so simply that it might actually get done.

Of the devices discussed in this article, the most gain per "unit of development effort" is probably the wet bulb temperature thermal sniffer. The potential gradient device for remote detection is a long shot--very useful it if works, but with a fair chance it might not work because of weak charges or spurious gradients. The biggest gain with a certainty of success is with the thermal marker, but the development of the marker is more complex than it might appear.

Sailplanes have been vastly improved over the last decade, but the improvements now are getting harder to make and far more expensive. It now seems an appropriate time to emphasize an alternative route--the improvement of instruments and techniques for locating and exploiting thermals.

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A UNIVERSAL TABLE FOR GLIDING

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INTRODUCTION

Some non-technical pilots or beginners are usually confused when faced with the problem of making a speed ring or computing final glide angles and speeds. Things become worse when the only known performance data are the best glide angle and corresponding speed.

The "universal" table was made for these people and gliders, but even highly technical people may find it useful when transforming a shower of test flight points into a polar or in analyzing non-quadratic drag characteristics caused by flaps, deep laminar bucket airfoil, flow separation, etc.

USE OF THE TABLE

For any particular glider, construct a similar table using the following steps:

1. Get (or choose) the values for the best gliding angle (L/D) and the corresponding speed (V^*) from literature maker's data or flight measurements. Compute the sinking speed at best glide speed

$$v^*(\text{m/s}) = \frac{V^*\ (\text{km/h})}{3.6 \cdot L/D} \quad \text{or}$$

$$v^*(\text{ft/min}) = \frac{87.93 \cdot V^*(\text{mph})}{L/D} .$$

2. Multiply columns 1, 3, 4, and 6 by this value of v^*.
3. Multiply columns 2 and 7 by the best glide speed V^*.
4. Multiply column 5 by the best gliding angle G.