

Improving Thermal Soaring Flight Techniques

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Introduction

Locating and utilizing thermals are obviously vital factors in efficient soaring, and yet it seems that rather little attention is being paid to the subject. When one considers the tremendous investment in time and money throughout the world devoted to improving the breed of sailplanes it does seem odd that much greater effective performance benefits obtainable through improving flight techniques are neglected. Perhaps it is really not surprising, 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.

Finding and using thermals in an efficient manner can be thought of as involving a system approach based on 1) knowledge of the characteristics of thermals, 2) developments in instrumentation, and 3) intelligent use of the knowledge and equipment. This article investigates these factors in hopes that it may help stimulate some enthusiasts to help develop this field in a logical fashion. Various of these techniques can easily and inexpensively be utilized by, and improved by, the average sailplane pilot.

Thermal Factors

General—In brief, thermals can be considered simply as rising volumes of air which carry aloft some air from near the ground while mixing somewhat with the environment. Thus a thermal has value to a sailplane because it represents a vertical velocity; for locating and using it, one can consider this vertical velocity, the factors causing it, plus other characteristics of air flow and symptoms of its origin near the ground. All these items must be considered in their relation to the surrounding environment and in their variations in the thermal throughout time and space. Obviously there are too many variables and interrelationships to permit detailed investigations, but some main features stand out.

Many of the points to consider stem from the fact that the initial roots of the thermal core are near the ground where the source of heat lies. There the thermal acquires characteristics associated with the ground air—higher temperatures, and more water vapor, space charge dust, turbulence, etc. Later on and higher up, that air parcel, although getting

somewhat mixed with the environment, will be distinguishable from the environment because the environment does not have those items in the same concentrations.

Buoyancy Factors—Temperature and Water Vapor

a) The buoyancy which powers the thermal depends both on the temperature and water vapor content, at all elevations; therefore measurements of temperature plus measurements or assumptions about water vapor can give information on buoyancy and on the future actions of the thermal.

b) Near the ground the temperature excess is large, and the water vapor excess generally small. High up in the thermal, the water vapor excess often becomes large relative to the drier air outside the thermal, and the temperature excess may be small (or even reversed). These characteristics have direct bearing on the use of thermal detector devices.

c) The air temperature in the root layer is closely related to ground temperatures—so predictions of ground temperature as it varies with ground cover, cloud shadow and topography and actual measurements of ground temperature will aid thermal seeking.

Flow Factors—Vertical Velocity; Lateral Velocity; Turbulence

a) Vertical velocity constitutes the payoff for the glider pilot and so is the most important thermal factor and warrants the best possible instrumentation.

b) Lateral velocity of inflow can help locate the thermal, especially the inflow in the root region. Knowledge of rotational velocity and lateral velocity within the thermal may assist the pilot in finding the optimum spiral.

c) Near the ground there is a lot of energy in small size turbulent eddies, so this turbulence could be deemed a thermal symptom. The situation is complicated because this initial turbulence decays and simultaneously turbulence develops from the thermal motions. Turbulence therefore may be of little value for locating thermals, but the way it affects other factors should be understood.

Root Symptom Factors—Dust; Foreign Bodies; Smells; Ions and Space Charge; Conductivity; Condensation Nuclei

a) Since the source of many vapors and particles is at the ground the thermal core can contain higher concentrations of these items than does the environmental air.

b) Space charge can be detected from a distance; the other items are only measured at the sensor.

c) Space charge, conductivity, nuclei, and chemical constituents can vary in time due to other factors than dilution with environmental air, which complicates their use as "identifiers".

Forecasting without Measurements

Consideration of topography, wind direction, stability and the whole synoptic weather situation and forecast can give clues as to the specific areas where thermals are most likely. This subject, which is beyond the scope of this article, is touched on in many articles in sailplane publications, for example References 1, 2, 3 and 4. In general, in non-flat land the high elevations provide earlier and higher thermals. Good source regions tend to produce upcurrents regularly—so a good spot to try is one where clouds have shown thermals earlier or experience has shown thermals on similar previous days.

Because of the regular production of thermals by good source regions, and because of the tendency for upcurrents to line up along the wind when there is a pronounced wind shear, it is often best to hunt for thermals straight upward or downwind from where you are already using one.

Forecasting with Measurements

Since the primary cause of thermals is the heating of air as it blows over the ground, exact knowledge of the surface temperature will help immeasurably in the locating of thermals. The temperature depends on the past history of radiation at that point, reflectivity, evaporation, heat conductivity, specific heat, and surface structure—so trying to guess at the temperature variations is usually impractical. However, the recent developments in infrared radiation equipment imply that a radiometer may be worth considering. Portable equipment is available to measure temperature remotely, but at present costs more than a sailplane. Using wavelengths in which the radiation from the air itself causes no problem, the instrument reads essentially temperature of the ground (or cloud) at which it points (say with a 2° beamwidth). For sailplane use, relative temperatures are adequate, which can greatly simplify the apparatus. The instrument would be pointed ahead and down; it could be programmed to sweep laterally or longitudinally, or could be rigid in the sailplane and the sailplane maneuvered as required.

With absolute accuracy, and with prior knowledge of the temperature lapse rate of the air mass, the ground temperature unit can even show whether or not any thermals would be expected over a broad region. Relative measurements would permit determining the most likely local source region.

This subject of infrared measurements is reviewed in the Proceedings of the IRE, September, 1959. Reference 5 describes a portable instrument and various manufacturers such as Barnes Engineering, Servo Corp. of America, and Williamson Development Co. have developments along this line.

Locating Thermals from a Distance

Ascertaining the definitive existence of an upcurrent while still a distance away from it requires a measurement based on radiant energy field of some type. Passive measurements

would be 1) visible light; the appearance of a cloud after it has formed or optical effects associated with the nuclei or contaminants in the rising air, 2) radiation in the infrared spectrum, from air which has a different temperature, water vapor, carbon dioxide, or ozone content, 3) acoustic radiation, or 4) the electrostatic field due to electric charge in the thermal. A non-passive measurement would be by radar where the energy source is at the sailplane—the echo would come from the radio refractive index fluctuations due to turbulent mixing in the presence of a gradient of water vapor. The radar and infrared techniques may offer real promise, but are beyond the scope of the average sailplane enthusiast to pursue and so will not be considered here. Infrared equipment for finding ground temperatures is more simple and practical. Acoustic methods do not appear operationally fruitful.

The visual use of cumulus clouds as thermal indicators is the main thermal locating technique. The cloud simply marks the top of a thermal. The detailed appearance of the cloud gives clues as to the upcurrent characteristics; large size, firm edges, and a dark, well-defined base usually mean a strong thermal. The most accurate way of getting thermal information from cloud appearance is to watch the shape and size change over a period of a few minutes.

When no cloud is visible, there may still be other things which show visually that a thermal is present. Sometimes condensation nuclei will become visible in an "almost cloud", when a true cloud does not quite form but the air does show a foglike character. Soaring birds or other sailplanes can mark a thermal. Dust and foreign objects swept up from the ground can also make it visible. A dust devil is an extreme example. Certain shades of dark glasses or polaroid glasses can apparently make "dusty" thermals more readily observable (and distant cumulus clouds too).

Even in fair weather there tends to be a weak net positive charge in the air near the ground, residing on ions collected on condensation nuclei. Thus a thermal may have a charge in it, of between 1 and 1000 elementary charges per cubic centimeter. By conductivity about half of the charge will leak away in 20 minutes near sea level (in just a few minutes at 3000 meters), so the charges from "old" thermals slowly disappear and only new thermals are charged. Theoretically, at least, this charge should be detectable from a distance by measuring the electrostatic field from the sailplane. Such potential gradient equipment has been developed for airplanes (see for example, References 6, 7 and 8) and in Reference 9 application to soaring is suggested. The apparatus can be light and relatively simple. Two standard techniques are available. In one the air voltage (relative to the aircraft) at a probe is measured: the probe is "coupled" to the air via a radioactive tip which makes the air within a few inches of it highly conducting, and this coupling lowers the probe-to-air resistance enough so ordinary electrometers and insulators can be employed. In the other the gradient at the surface of an object (say the wing or fuselage) is detected by cyclically covering and uncovering a conductor and noting the bound charge that enters and leaves it. In either case, two sensors must be adjusted and located so that the potential gradient caused by charges on the sailplane affects each probe equally and so is automatically cancelled when the probe voltage differences are measured.

There is a vertical fair weather field of about $\frac{1}{2}$ to 1 volt per centimeter and the instrumentation must not be confused

by this field. In thunderstorms the charges in clouds can give gradients outside clouds of many hundreds of volts per centimeter but during such conditions the cloud appearance tells even more than electrical measurements would. In ordinary conditions, a recommended method would be to measure the gradient along the direction of the line of flight, for this line stays close to horizontal (say one radioactive probe at the nose, one at the tail). Then if the sailplane is flown in a direction making the observed gradient maximum, it should be heading toward (or away from) the charged thermal.

Figuring out a Thermal from Measurements of Vertical Velocity

Every soaring pilot has wished he could fly into or through a thermal and then know immediately just where to maneuver in it to get the maximum climb and know whether it will be getting stronger or weaker. Measurements from the sailplane, coupled with intelligent interpretation, can go a surprisingly long way toward providing the information.

The definition of a thermal—and its use to the soaring pilot—is its vertical velocity. Therefore, vertical velocity is worth measuring well and the state of the art permits this.

The vertical velocity of the air, rather than the sailplane, is what the pilot really wants. A standard rate of climb indicator shows the vertical motion of the plane. The indication is corrected for airspeed changes by a “total energy” venturi or diaphragm unit, and can be corrected by drag loss (ordinary sink) by a throttled pitot. The basic subject is reviewed in Reference 10 and the new total energy device is discussed in Reference 11. Reference 12 shows how to improve the total energy unit still more by filtering out the effects of the longitudinal turbulence on the “total energy” correction. References 13 and 14 offer further pertinent information. To summarize the situation now, excellent variometers are available, and with special correction techniques they can give satisfactorily fast and accurate readings of vertical air velocity under any typical flight condition. The electric variometers are especially fast acting, such as the Crossfell unit (see Reference 15) any of which can be obtained with a total energy diaphragm corrector.

The biggest single improvement in thermal soaring performance can come from optimizing the use of the variometer. This means maneuvering the sailplane jointly to get the maximum vertical motion and the maximum information about the thermal. The average pilot does not know how to get back to a particularly good spot in a thermal through which he has just traversed. This requires a good memory of the variometer record and experience in precision maneuvers. To obtain a good memory a logical tool to utilize might be a recorder which plots a continuous trace of the variometer reading, within easy view of the pilot, with about 100 seconds of the record visible at one time. With judicious use of a pilot-operated event marker on the recorder to show the sailplane is entering a cloud or on the north edge of a spiral, this recorder can greatly assist the pilot in determining the thermal structure without lost motion. Even without a recorder it is not difficult to remember the readings at the four cardinal points during circling flight, so as to estimate the direction to the thermal center.

There is a large variety of useful precision maneuvers which the pilot can compute and practice in calm conditions. Most would involve tight precision turns, at fairly low velocity, at bank angles of 30–45°, for strong, sharp thermals—and even

a wingover or Immelmann may be optimum for a fast efficient direction change. For large thermals more intricate probings would be appropriate. For example, with an 18 second turning rate, and a turning radius R of about 65 meters (a 30–45° bank), a 270° turn to the left then a 90° turn to the right brings you back along the original flight line about 18 seconds after you start the maneuver, meeting the original line a distance $2R$ back. For setting up a parallel reverse course, a 180° turn, in 9 seconds, establishes a reverse course $2R$ distant from the original course. If your bank angle changes, say from 45° to 30°, the turn radius changes by over 50%, so precision maneuvers must be carefully done. Gyro instruments are helpful. The total flight patterns you select will depend on what the variometer and other instruments are showing you. In most cases you will want a straight pass through the thermal so as to learn as much about it as possible—but this is only best if you interpret and utilize the information properly. Sharp turns are most efficiently done at slow speeds.

Another aid for visualizing exactly what is in a thermal is to mark it as you fly through. You can release paper, balloons, bubbles, or smoke. The bubbles and smoke can be released continuously by small special gadgets. The bubbles may be the best method because each bubble remains for a minute or two as a discrete entity, while smoke can quickly diffuse until it is invisible. To help preserve visible smoke, it can be released along the outer trailing edge of the wing where it is rolled up into the tip vortex and protected from diffusing until the tip vortices interact and break up.

Thermal Growth Measurements

If the air within a thermal is much warmer than the surrounding air at the same level, the thermal has buoyancy and will be accelerating, becoming better and better for the soaring pilot. Because water vapor is lighter than air, if the thermal has significantly higher humidity than the surrounding air at that level it will have buoyancy just as though it were warmer, and thus be accelerating (a thermal is more humid than the environment, and more so the higher it gets, reaching 100% at cloud base). The drag of the surrounding air slows down the upward acceleration, so the measurement of buoyancy is not a perfect predictor; also all the environment and thermal characteristics should be considered as they vary in height (perhaps in one minute the buoyant bubble will rise to an environment where it is no longer buoyant). Many of these factors are as yet the subject of considerable controversy in convection theory, but from the standpoint of the sailplane pilot one can summarize: a thermal with good buoyancy is likely to stay as strong or get stronger in the next minute or two, while a thermal with little buoyancy or even negative buoyancy is likely to weaken.

To summarize the acceleration due to buoyancy (neglecting drag, which has an unknown effect at the center of a thermal):

$$\text{Acceleration} = g \left[\frac{T_i - T_o}{T_o} + 0.6(w_i - w_o) \right]$$

where g is the acceleration of gravity, T is absolute temperature, w is the mass ratio of water vapor to air and the subscript “ i ” and “ o ” refer to inside and outside the thermal respectively. In a typical case, 1°C of temperature excess will cause an upward acceleration of about 100 meters per minute velocity change in one minute, and near cloud base the water vapor buoyancy effect may be about as big.

Measuring the buoyancy terms requires measuring T_1 , T_0 , w_1 and w_0 , all at the same height. One can get useful information by measuring only T_1 and T_0 because one knows that the moisture buoyancy term is always positive; the humidity inside the thermal is always greater than outside, and the maximum amount can be predicted as a function of height reasonably well from previous knowledge of air mass characteristics and thermal theory. In temperature measurements dynamic heating of the probe should be corrected by means of a vortex housing. The big problem in measuring T_1 vs T_0 is that your height changes as you traverse a thermal, and so you encounter temperature changes due to the temperature gradient from adiabatic heating of the atmosphere. What you want is a "potential temperature" thermometer, one corrected for altitude by subtracting about 1 °C per 100 meters. One approximate way to provide this is to have a temperature difference sensor measuring the difference between outside air and air contained in an expandable balloon or envelope. As you ascend or descend the balloon air expands or contracts and cools or heats adiabatically, providing a compensated reference temperature. Because of conductivity heating at the balloon walls, an error will slowly appear, so with this system one would adjust for zero difference just when entering a thermal, and the readings would be valid for perhaps a minute or so later. It is possible that the air capacity for the variometer would suffice as the balloon, "breathing" rather than expanding, but its small size might make conductivity effects too great. Alternatively, an altitude correction can be made electronically (with some complexity) with the altimeter.

Turn Direction Information

If the center of a thermal is warmer than the surroundings, then logically one could measure the temperature difference between the wing tips and so determine which way to turn to head toward the center. Many people have constructed "thermal sniffers", but definite accounts of their successful application are hard to find (see References 16, 17, 18 and 19). The previous discussion of buoyancy points out one problem—a thermal can be buoyant due to water vapor without being warmer inside. When the thermal is warmer, it may be so by only an average of say $\frac{1}{2}$ °C in 1000 meters—a small amount to measure—and yet random turbulent temperature fluctuations exceeding this amount can be present as "noise" on the instrument. Thus following the "thermal sniffer" would have a weak tendency to direct you properly, but with many false instructions included. Finally, when you bank toward an imagined center, the lower wing goes into warmer air—since the vertical temperature gradient is generally an order of magnitude greater than the horizontal temperature gradient, making the pilot observe a false favorable indication. Reference 20 discusses recent developments with a "thermal sniffer".

There are improvements in tip temperature sensors to overcome some of these problems, but the value of even an ultimate unit is still a question. To eliminate tip speed dynamic heating effect and tip elevation differences, Temple developed a trial system where at each tip the temperature difference between the present time and one second earlier is measured.

Other gradients than temperature may be more meaningful. Consider water vapor content. It may vary by 500 percent across a thermal, while temperature varies only by a fraction

of a percent. Near the top of a good "dry" thermal the moisture in the surrounding air may be 2 grams of water per kilogram of air, and 8 grams per kilogram in the thermal center. A fast responding water vapor sensor at each wing tip might thus indicate the direction to the center of the thermal far more reliably than a temperature activated "thermal sniffer" could, even though turbulent fluctuations will still cause lack of reliability. Fast water vapor sensing poses instrumentation difficulties; tiny wet-bulb thermistors are feasible, and several experimental methods show promise.

Other variables could conceivably also be used. Ions, pollutants and conductivity are characteristic of the inside of thermals due to the thermal having its original roots in air representing surface conditions. Thus variations of these could give thermal orientation clues.

The difference in vertical velocity between the wingtips also obviously will show the direction of the thermal center (with some "noise" signal, however). Accurate measurement of the velocity gradient in a sailplane is difficult, although in extreme cases a strong lifting of one wing shows the pilot which way to turn. It seems likely that an instrument indicating this variable qualitatively could be developed, at least for use in straight flight.

Optimizing Flight Maneuvers

Some of the factors in maneuvering in thermals have already been discussed. For improving your knowledge of a particular thermal, precision maneuvers are a must. The optimum maneuvers in probing and utilizing the thermal may be rather complicated to compute, as the factors of instrument performance, turn radius, turn time, sailplane performance and control, and drag energy loss should all be considered with respect to meteorological factors.

In the case of true dynamic soaring (getting energy from horizontal or vertical gusts) performance gains are conceptually feasible but actually not practical. This subject is thoroughly covered in Klemperer's classic paper, Reference 21.

For determining the best speed for flight between thermals, the use of an optimum speed selector is now standard. It is based on the downcurrent strength, the sailplane performance curve, and the expected strength of the next upcurrent. With the drag correction device built into a total energy variometer the speed selector can be redesigned and will immediately indicate the optimum speed (rather than indicating just faster or slower) and so permit faster and more decisive flight corrections (see References 10 and 22). Various mechanisms can be constructed to make the indication even more readily available to the pilot—say having optimum speed indicated as a second needle on the airspeed indicator—and in the ultimate a servo could even be made to supplant the pilot. Reference 23 cites an automated approach.

In any case, in rough air the effective glide ratio of the sailplane can be increased by fast optimizing control. This can be considered a form of simple dynamic soaring. However, the magnitude of the effect is very small. An error of 5 mph, or even 10 mph, from the optimum speed makes surprisingly little difference in the effective glide ratio or average flight speed in thermal conditions. For example, with a Schweizer 1-23 in a 4 fps downcurrent in a 5 fps thermal situation, the net cross-country speed decreases only 2% if the pilot flies at 70 mph or 90 mph instead of the optimum 80 mph.

Horizontal gusts constitute a different situation. Here fast speed (altitude) control may be more beneficial, for it is the

entering or leaving the new flow regime which is important, rather than the time in it. Because lift is a non-linear function of velocity, the sailplane obtains more energy as its airspeed is increased in a horizontal gust than it loses in an identical airspeed decrease from the same original speed. Fast and accurate pilot control of optimum airspeed, perhaps aided by a "G" sensitive bob weight in the control system to emphasize G-forces, can thus presumably increase the effective sailplane performance—but the net effects would be small except under unusual circumstances of large variations in the horizontal and vertical motions of the air (see Reference 21).

The Future

With some practical, available, inexpensive instrument improvements, and with some careful practice a pilot could decrease his sink between thermals, have a better chance of locating the position of the next thermal from a distance, and with one pass through the thermal could estimate its future actions and select and return to its best part. In a typical flight the gains from these techniques might greatly exceed the performance differences between typical contest sailplanes.

The most vital instrument is a fast variometer with velocity change and drag corrections and with an optimum velocity unit. With this instrument, and with some training in maneuvers, big gains could be made. For further gains, but with more complex or new (but still practical) instrumentation, try adding a velocity recorder, presenting optimum speed automatically, installing a temperature buoyancy device, fitting on a bubble generator, adding a potential gradient "director", and devising water vapor gradient instrumentation. The infrared ground temperature instrument may prove economically feasible—and it offers such great promise that it should be emphasized. No doubt other aids will come to mind as this subject is studied further, and no doubt some of the exotic devices which now seem impractical will be developed to practicability for other purposes and then be available for soaring.

The pilot who pursues this subject can significantly advance soaring and meteorology, and may simultaneously get superglider performance out of his ordinary sailplane.

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