THERMALS: A PROPOSAL FOR THEIR BETTER UTILIZATION AND DETECTION

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I. Introduction

The purpose of this paper is to examine the periodic displacements of the yaw string in certain types of thermal, a phenomenon observed by the author on numerous occasions when flying in windy and turbulent conditions. The objective is to identify the cause of these yaw string displacements, and to consider a modified technique of thermaling designed to better utilize the specific kind of updrafts discussed in this submission. The paper will also deal with the controversial issue of lift-related variations in airspeed. A further objective is to explore the possibility of developing an audio-variometer stereo system capable of picking up the differential lift acting on the extremities of the left and right wing respectively, and thereby assist the pilot in the detection of thermals, and once found, to make better use of them.

II. History and background

The initial impetus to the study was given by a flight undertaken on August 17, 1989 to satisfy the Silver C requirements for a flight of no less than 5 hours. The writer was instructed to land no later than 19:15 hours E.D.T. and to remain within sight of the attending Official Observer. The take-off took place shortly before noon. It was a sunny day, slightly breezy, and the base of the cumulus clouds encountered during the flight, which lasted 7 1/2 hours, reached 4500 feet AGL.

After about 6 hours the boredom of drawing steady circles in the vicinity of the airfield was broken by the startling discovery that the movements of both stick and rudder had assumed a cyclical pattern, closely synchronized with pulse-like swings of the yaw string, primarily in the direction of the higher wing. When attempts to suppress these movements resulted in a very noticeable decrease in the rate of climb, it became clear that the phenomenon could not reasonably be attributed to uncoordinated flight.

After further experimentation with this technique, henceforth referred to as "pulsing," the author was able to drastically increase the range of his flights. Finally, in 1992 he submitted his findings to Gerhard Waibel of Alexander Schleicher Segelflugzeugbau, Germany, who encouraged him to present his work to OSTIV.

III. Tall thermal plumes – a valid model?

The author's model of tall thermal plumes is sometimes questioned by those who support the vortex-flow structure of thermal bubbles. Since many of the concepts advanced in this paper are based on thermal plumes, this criticism should be dealt with at this point.

The writer believes that while thermal bubbles are quite common, they are not the only form by which warm air may rise.

1. As it is impossible for a glider to rise above a thermal bubble, only a continuous thermal will allow an initially lower glider to out climb another one.

2. When flying from one developing cumulus cloud to another, the pilot may lose several thousand feet in altitude, only to make up for this loss well below the next

cloud chosen. What are the probabilities of regularly arriving at the precise moment when a new bubble happens to go by, and sometimes to be so lucky for hours on end?

3. Just because the ground source of the thermal is exhausted, the latter does not necessarily turn into a bubble. The ratio of height to width of a typical thermal bubble is roughly 1:2. Unless the remnant plume undergoes considerable contraction, it is likely to be far too high for a vortex flow to develop.

IV. The lift profile of tilted thermals

Because the sink rate of a sailplane does not allow it to keep up with the rising air around it, it is common practice when flying in a tilted thermal to shift one's circle upwind by an appropriate distance on every turn in order to prevent the glider from being thrown out on the downwind side of the thermal. These corrections are one reason why the control movements assume a cyclical character. However, to explain the periodic deflections of the yaw string, we must look more deeply.

Figure 1 shows a thermal convected downwind. The windspeed is 5 knots and the warm air rises at the same speed. If we ignore for the moment the effect of the wind gradient, as well as the variations in the vertical acceleration of the buoyant air, the slope angle of the thermal will be 45 degrees Dissecting the thermal at right angles to its center line along points A_1-A_2, we obtain a roughly circular cross-section as shown on the left.

The lift is assumed to be strongest in the core and gradually diminishing towards the fringes. This is indicated by small + symbols of varying density, as well as by arrows of differing length in the thermal plume itself. For the present purpose we shall call this the "lift density" of the thermal. (In fluid mechanics it is more properly referred to as "momentum flux.") If we join the points of the arrows in section A_1-A_2 we get what may best be described as a "lift profile."

It is evident that a glider could remain in even lift by flying true circles only if the thermal remains perpendicular to the ground. If there is only a light breeze, the glider will traverse the thermal at some angle other than 90 degrees to the latter's center line (see dashed line B_1-B_2), resulting in an elongated cross-section. It should be noted that the lift profile is no longer symmetrical as it was in the previous case. This is, among other factors yet to be considered, because the warm air on the left of the plume has traveled a shorter distance from the ground than that on the right, even though the altitude is the same.

Additional distortions of the lift profile occur as the rising warm air causes cooler air to be drawn into the system from the sides. While this entrainment takes place in the absence of any wind, it can be counted on to distort the lift profile even more in its presence.

Whatever the case may be in the light of above findings, the mere fact that the cross-section B_1-B_2 in Figure 1 is oval in shape, dictates that if the pilot wishes to optimize his rate of climb, he must make constant

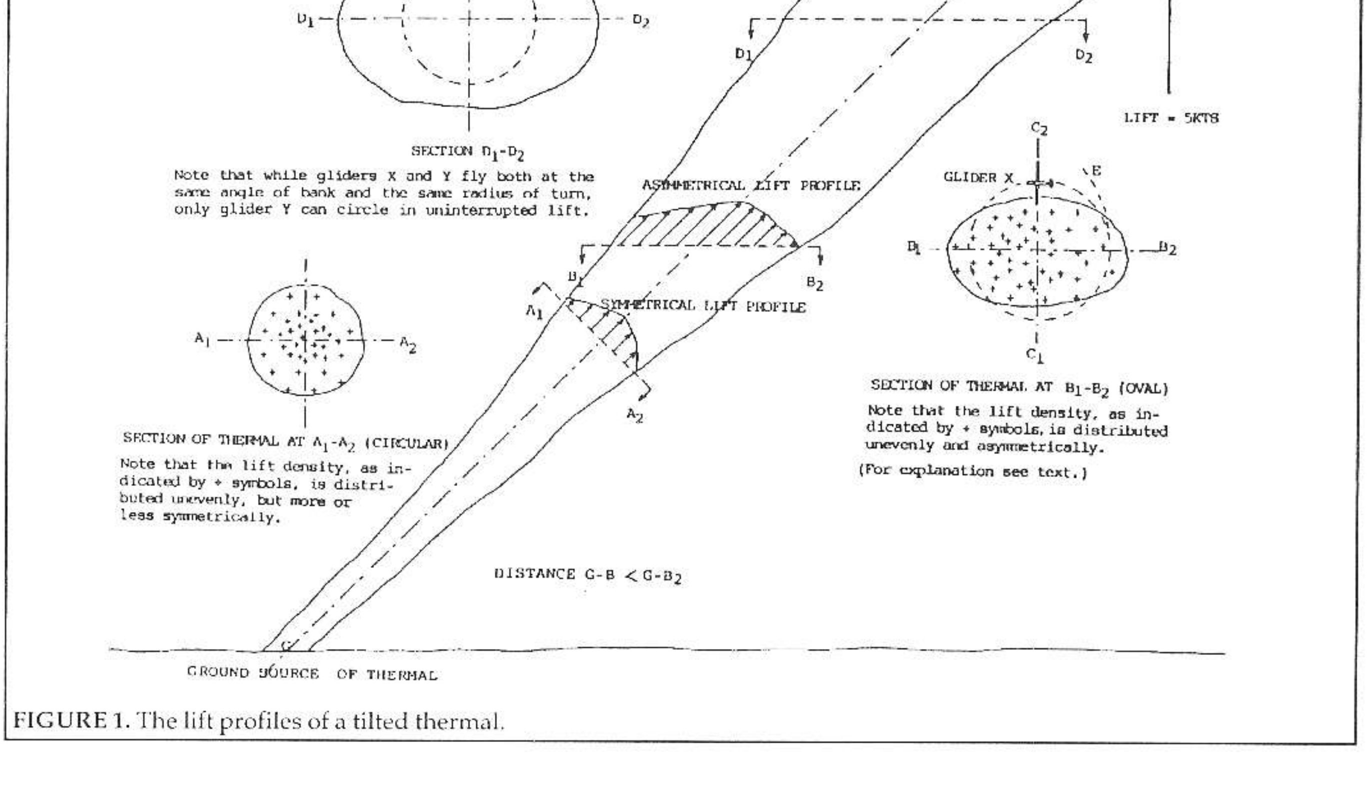

FIGURE 1. The lift profiles of a tilted thermal.

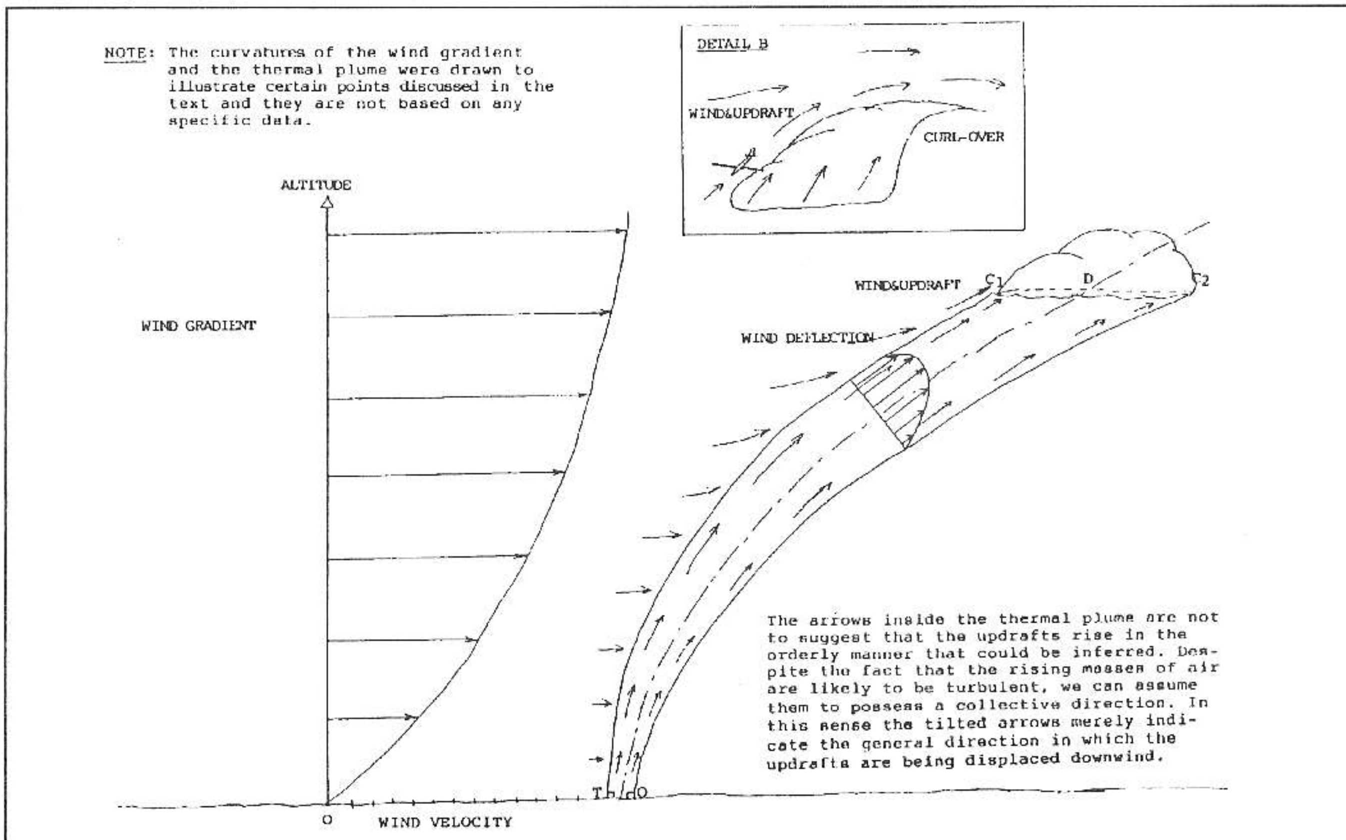

FIGURE 2. The effect of the wind gradient and other factors on the slope angle of a thermal plume.

corrections in the radius of turn to remain in the most concentrated areas of lift. It should be noted that a lift profile taken at right angles to section line B_1-B_2, namely between C_1 and C_2, would look quite different from the previous one. In fact, if this lift profile were to be drawn on a baseline as wide as before, it would be inverted at its extremities. This means that if glider X is already at a steep angle of bank, it will break out of the thermal at points C_1 and C_2 and get into sink. On the basis of his sharply fluctuating variometer readings the pilot may seek to solve the problem by shifting his circle. If, by applying conventional techniques, he reduces his angle of bank when in lift (positions B_1 and B_2), he will be dumped out of the thermal altogether (point E). Seeing glider Y gaining altitude rapidly above him, he will be misled to believe that his friend latched onto an isolated thermal bubble. Obviously, the pilot of glider Y, who is circling higher up in the wider part of the thermal, does not have any trouble staying in lift throughout his turns. The pilot of glider X could try to alleviate a bad situation by well-timed rudder deflections, i.e. by pulsing, and thereby approximate the shape of the cross section referred to earlier (B_1-B_2).

Figure 2 introduces several additional factors for our consideration. On a windy day the masses of warm air rising from the ground are accelerated from a standstill in both a vertical and a horizontal direction. Because this acceleration in two directions occurs at different rates, the thermal plume is displaced downwind in a curve. The wind gradient, as represented by the line graph on the left, will greatly amplify the curvature of the plume. While the wind near the ground attacks the thermal almost at right angles, it tends to reinforce the lift further up as the curvature increases. This may be one of the reasons why the most vigorous lift is usually found on the upwind side of the cloud. All of these factors could contribute to further distortions in the energy distribution in a tilted thermal as suggested in the asymmetrical lift profile B_1-B_2 in Figure l, and thus be instrumental in the rhythmic control movements observed by the author. Note the two comments in Figure 2. It may be argued that since we deal with individual particles of air, the wind cannot attack streams of air as it does an airfoil. As the "curl-over cloud" in detail B of Figure 3 shows, streams of air have a sufficiently cohesive structure to be attacked as an aerodynamic entity, notwithstanding the fact that the latter has internal motion. Smoke plumes tilted downwind are also cited as visual evidence in the same context.

V. The effect of tilted thermals on the rate of climb

To find how deflected updrafts may affect the rate of climb when, in the course of a full turn, we fly around the confines of a tilted thermal, let us look at the path of a glider in a narrow, but vertical thermal at a bank angle of 45 degrees. For the present purpose it will help us to view the glider as flying inside a huge bottomless bowl

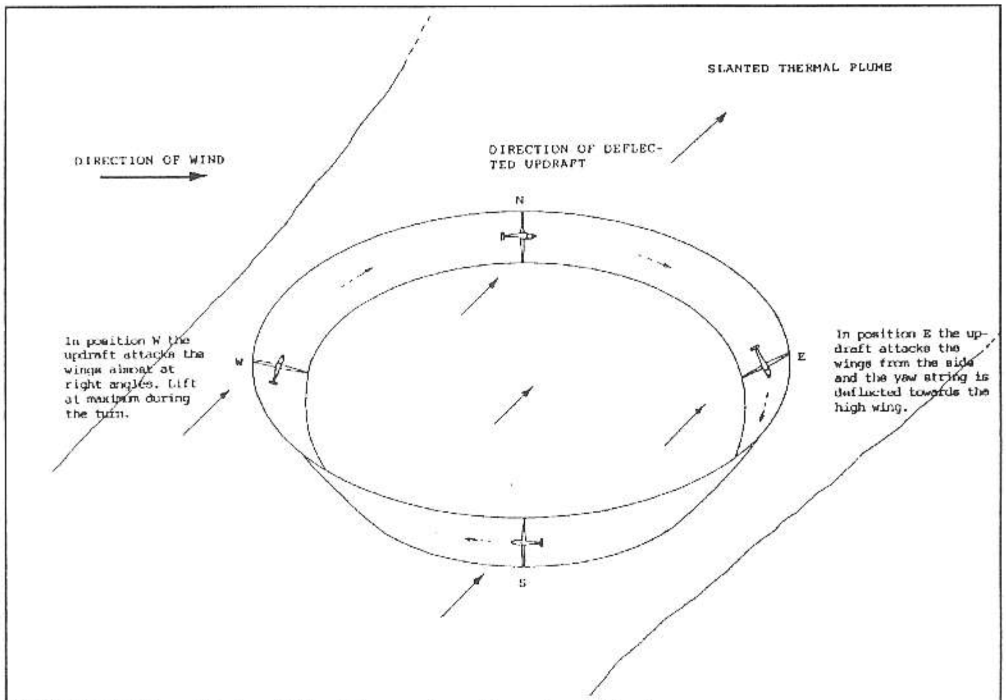

FIGURE 3. The effects of tilted thermals on the rate of climb.

causing the wings to cut through shifting layers of air several meters apart. The very fact that when thermaling in turbulent conditions, the pilot must constantly move both stick and rudder, shows the abovementioned "steady drift concept" seriously wanting. On the other hand, the observations made in regard to Figure 3 offer a plausible explanation why, when flying in a tilted thermal, the variometer often registers varying lift in a cyclical pattern. If we happen to share such a thermal with another glider at the same altitude, we may get the impression of being engaged in some kind of aerial roller-coaster ride, without either of the two

as illustrated in Figure 3. In the absence of any wind, the angle at which the updrafts attack the wings from below would not change regardless of the glider's position. However, in a thermal sharply tilted downwind it would appear that with the direction of the updrafts given, the following sequence is likely to unfold:

Position W: The slanted updrafts attack the wings from the left and almost at right angles to them. This will maximize the rate of climb.

Position N: The updrafts attack the wings at a relatively sharp angle from behind, thereby causing the rate of climb to diminish.

Position E: The updrafts attack the wings at a very acute angle from the right of the glider. This will reduce the rate of climb to the minimum during the turn.

Position S: The updrafts attack the wings at a fairly steep angle from the front, thereby causing the rate of climb to increase again.

Conclusions: When circling in slanted updrafts of regular lift density, any variometer fluctuations may be caused solely by the rotational position of the glider in the thermal. Under these conditions any attempts to overcome the fluctuations by shifting the center of the turns will likely prove counterproductive. The author is well aware that the sequence described above is not in agreement with the claim often made in soaring manuals that the turns of an aircraft remain totally unaffected by the wind. While the latter applies where the entire air mass surrounding the plane moves in the same direction, the claim does not hold true in situations where the flow of air is disturbed by localized updrafts and other forms of wind shear. This is particularly the case where the glider is circling at steep angles of bank, thereby

planes really gaining on the other. Moreover, we frequently even hear rhythmic variations of certain air noises which seem to reflect these wave-like movements.

VI. The causes of periodic yaw string displacements

When a sailplane circles in a thermal at steep angles of bank, the relative airflow could be viewed as having two components, the major one being derived from the forward motion of the plane, the other, although very much weaker, arising from the updrafts attacking the plane from the side. The direction of the latter component is determined by the angle of bank and the slope angle of the thermal. Under these conditions the position of the yaw string may be considered as the resultant of these two components. Where the slope of the thermal lies roughly in line with the pitch axis of a banked glider, the yaw string will, unless corrective action is taken, be displaced towards the high wing (position E in Figure 3). It should be noted that, provided the bank angle is steep enough, the displacement of the yaw string may also occur in a vertical or near vertical thermal if the lift suddenly increases.

If the pilot upon entering the downwind sector of a tilted thermal fails to compensate for the swing of the yaw string, the glider will tend momentarily to slip into the turn. Since the yaw string usually returns to its center position after a brief pause on its own accord (somewhat like the aberrant swing of a windsock), the pilot is apt not to react to it. Because the author considers these cyclical displacements of the yaw string quite significant, he proposes to call this sector of a tilted thermal the "slip sector." In fact, the pilot may wish to utilize the lift better by entering the slip sector with a reduced angle of bank if the thermal is wide enough to allow this. The objective is to position the wings at a more advantageous angle of attack in relation to the slanted updrafts. The principle involved can be illustrated by the following hypothetical case: If in Figure 3 we were to release a stream of balloons into the tilted thermal, they would strike the wings of the banked glider almost squarely from below in position W, whereas in position E they are likely to miss them altogether.

VII. Lift-related variations in airspeed

There have long been claims by glider pilots that a sailplane speeds up in lift and slows down in sink. Regarding this point, the author queried a number of very competent pilots, among them several aerodynamicists. Some of them were quite sure that such speed changes occur, others that they do not. Very few of them offered any convincing proof one way or the other.

To shed some light on this question we could look at the imaginary bottomless bowl in Figure 3 as a continuous airfoil quite apart from the sailplane. Let us assume that we could somehow vary the slope angle of the thermal. If we begin with a completely vertical updraft, the airfoil would, provided it were equipped with some means of stabilization, remain in the horizontal attitude shown. However, if we would change the thermal from its initially vertical position to the tilted position illustrated, the airfoil would realign itself with the flow of air, and thus be lifted up on the side marked W. If this is indeed how a sailplane reacts to the same conditions, it is easy to see why it would be subject to cyclical fluctuations in airspeed. In a situation where the lift equals the sink rate of the glider, the latter will, so to speak, "run downhill" for the first half turn (W-N-E), thereby causing it to speed up, and then climb "uphill" at a gradually slowing pace through the second half of the turn (E-S-W). If the lift is greater than the sink rate, the picture would essentially remain the same, except that each of the four positions illustrated will be reached at an altitude higher than the preceding one.

There may also be forces at work that arise from the aerodynamic design of a glider. To ensure longitudinal trim at a predetermined airspeed, the nose-heaviness designed into the aircraft is counteracted by giving the tail-plane a negative angle of incidence. In position N of Figure 3 the slanted updrafts will attack the tail-plane from behind in such a way that the latter's negative angle of incidence causes the tail to be lifted upwards. If this motion is not corrected, the glider will speed up. In position E the tail-plane's angle of incidence has the opposite effect, causing the glider to pitch up and to slow down. In the more general case where a glider, which is trimmed for a given airspeed and angle of attack, suddenly enters an area of lift, the reaction of the tail-plane will be to rise, thereby increasing the airspeed. A further factor derived from Figure 3 is that in position S the pitot tube is poised to pick up the slanted updrafts, whereas in position N it is not. Where the angles involved are extreme enough, it will introduce an error in indicated airspeed just as it does during a side slip.

VIII. The technique of pulsing

Whether or not the technique of pulsing is really viable will be decided by other glider pilots. Therefore a brief description of this technique is given below for those who wish to put it to the test.

The first thing one must do is to determine the character of the thermals which are prevailing on the day. If during several well co-ordinated turns the yaw string remains neatly in place, it would be counterproductive to do anything other than keep the glider centered. However, where the yaw string refuses to settle down, pulsing is likely to yield good results, especially where the swings of the yaw string take on a rhythmic character and the displacements are predominantly towards the high wing. In this situation it is best to move the stick only as much as is needed to maintain constant airspeed and the bank angle chosen. The objective is now to correct all significant deflections of the yaw string with short, energetic pedal thrusts. In response the yaw string should return instantly to its center position without overshooting. When one does run across the right type

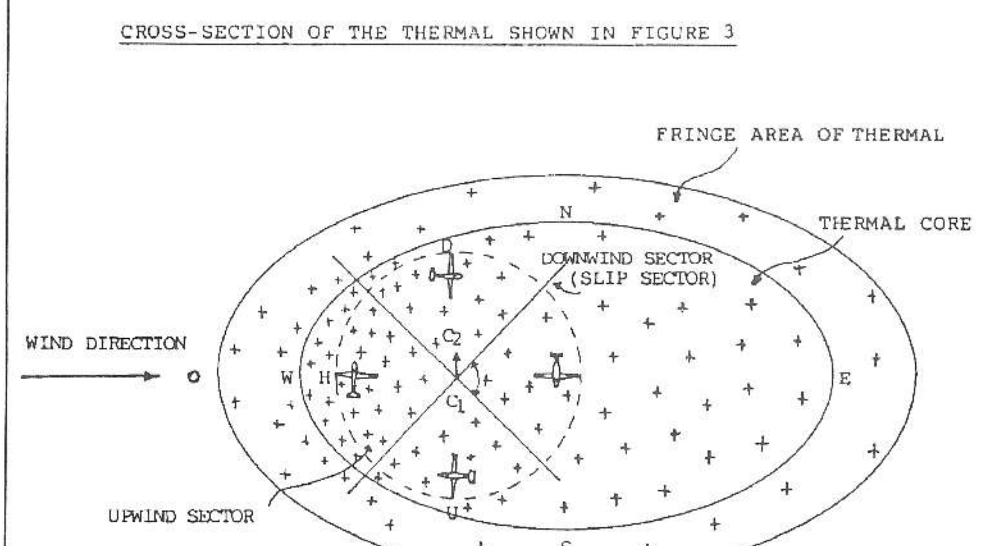

FIGURE 4. Thermaling in an uneven lift profile.

of thermal (not all irregularly shaped thermals are suitable) and one manages to establish the right pulse rhythm, the results can be astonishing. To gauge one's success, one need only stop the pulsing temporarily. Once the technique is mastered, it can be refined with additional aileron and elevator inputs, although the emphasis will remain with rudder control.

Obviously pulsing at excessively low airspeeds is a sure prescription for unintentional spins. Therefore the airspeed must never be allowed to drop below the minimum sink speed listed by the manufacturer for any given bank angle, a practice which is prudent in any case. Pulsing should be practiced at a safe altitude and well away from other sailplanes.

IX. Do rough conditions require rough flying?

The following example is given to illustrate the technique of pulsing in a practical context and to show how it differs from conventional methods of thermaling. The description will also serve as a summary of the key points discussed so far.

Figure 4 is a cross-section of the same thermal shown in Figure 3. The dotted circle indicates the position of a glider in the most concentrated lift of the thermal. A pilot using the traditional method of thermaling will fly even, well-coordinated turns at a constant angle of bank centered on point C_1. Because of the uneven lift profile (energy density) the variometer may fluctuate, say, between 4.5 kts in the downwind sector and 6.0 kts in the upwind sector. This will cause the pilot to increase the bank angle in the downwind sector (reduced lift) and to decrease it in the upwind sector (increased lift). While the pilot will succeed in leveling the extremes of the variometer readings by shifting the center of his turns upwind to position H, his average rate of climb will be less than it was before. The pilot will probably conclude quite mistakenly that the lift has generally gotten weaker in the meantime.

If a pilot were to apply the principles put forth in this paper, he would proceed very differently. To begin with, he would not be fooled by the fluctuations of the variometer as he accepts them as an unavoidable condition when flying in tilted thermals. He will also try to stay as close as possible to the upwind side of the thermal as he can, because this allows him to make use of the strongest concentration of lift. When traversing the upwind sector of the turn it will not bother him that he can only do so by flying at a steeper and "less efficient" bank angle. Quite to the contrary, although he will pull up and slow down in this area of stronger lift, he will reduce his angle of bank only as much as is absolutely necessary. This approach is his first break with traditional practices of thermaling. His reason for doing so is that he seeks to have the slanted updrafts, which come from his left in position W (which lies upwind from position H), attack his wings as squarely as possible. When he flies into the slip sector of the turn, the pilot makes his second tactical change. Rather than increasing his angle of bank in weakened lift, he reduces it. He does so for two reasons:

1. He does not wish to shift the center of his turns to C_2 as this would force him out of lift later on, probably near point D.

2. He wishes to make the best of the slanted updrafts which are now stroking the underside of the wings at too low an angle as it is.

While going through the slip sector, the yaw string will likely be displaced towards the high wing. Because having reduced his angle of bank just moments earlier, the pilot must take care not to be carried outside the thermal at the end of the slip sector. To combat this problem, and at the same time reenter the yaw string, he quickly increases his angle of bank again, preceded by a well-timed, energetic rudder pulse to the right. This will result in an almost jerk-like movement of the glider to put it on the right course for the upwind sector of the turn. The obligatory drift correction follows as the pilot heads into the wind. Both actions will set the glider up to fly deeply into the "corner" of the most active part of the thermal along the elliptical path U-W-D. It should be noted that this path is significantly longer than the ground path U-H-D. More time spent here means altitude gained. The sharp increase in the curvature will require the pilot to once again steepen the angle of bank which, as pointed out earlier, he ought to do anyway if he wishes to make the most of the slanted updrafts now attacking the wings once again squarely from his left. His real test here will be to strike the most efficient balance between a low airspeed and a high angle of bank.

No other statement on the art of soaring has intrigued the author more than Helmut Reichmann's astute observation that rough conditions require rough flying.

X. Proposed instrumentation for thermal detection and utilization

As evolution did not see fit to equip man with natural wings, we did not develop any capacity to locate thermals instinctively, or to judge their concentration when we find ourselves in their midst.

When one flies with hawks, turkey vultures, and eagles, especially on windy days, one can observe how these birds literally feel out the updrafts spilling around their wings by spreading and twisting the outer feathers.

The writer often speculated what it might be like if, with his arms extended, he could somehow reach into the wings of his sailplane to actually feel the updrafts 7 1/2 meters on either side of his body and perhaps even twist the ailerons by hand.

Thus the question the author wishes to put forth for consideration is, whether it may be possible to extend our senses by suitably designed instrumentation. Early in 1991 he tried to accomplish this by means of a small angled mirror assembly which, suspended from the instrument panel, would detect even the slightest lifting of one wing over the other. It was hoped that during straight flight the device would give the pilot some indication on which side a thermal was more likely to be found. After several flight trials the experiment was abandoned for two reasons:

1. In its original undamped form, the mirror assembly, which was free to swing about the roll axis, was only usable on very calm days.

2. The device causes the pilot to concentrate on the instrument panel.

The failed experiment showed that the problem must be solved by more sophisticated means. The solution now proposed is to install highly responsive lift sensors in each wing tip, thereby allowing the pilot to detect even minute differences in lift within the wing span of the aircraft. If we simply expand the idea of the mirror assembly, the devices in question could take the form of two separate netto-variometers. A much better solution would be to use two air-attack meters instead, which are capable of measuring the actual strength of the updrafts acting on the wings at their outer end.

Whichever of these approaches may prove the most effective, the system envisaged would generate two separate audio-signals which are picked up by the pilot over a headphone set in stereo. This would enable the pilot – somewhat like our feathered friends – to distinguish between the lift conditions as they exist at any given moment at the left and right wing tips some 15 meters or more apart. Because the pilot would be hard-pressed to decide which one of the two incoming signals heard, left or right, is the more intense, the system should be programmed to suppress whichever signal happens to be the weaker one of the two. In the event that the system were also able to measure the difference in air temperature between the wing tips, it would be best to have the two inputs (i.e. lift + temperature) reinforce each other, rather than confuse the pilot with a separate set of signals for each parameter.

If an Audio-Variometer Stereo System as outlined above could be made to work, it would bring the glider pilot one step closer to experience physically the very elements that support his flight. By extending his senses into the wings like a soaring bird, he may even learn to fly like one: by instinct, rather than intellect.