The Influence of Acceleration On the Sink Rate of a Sailplane And On the Indication of the Variometer

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This article is a summary of conclusions drawn from theoretical work, wind tunnel experiments and in-flight measurements; work carried out over several years. It was the aim of this research to explain the differences which exist between the real response of the total energy variometer and its ideal behavior.

We believe that the results which have been assembled here in concise form will help the interested pilot to better understand the response of his variometer, or to improve an existing system which does not satisfy him.

Influence of Acceleration on the Sink Rate of a Sailplane And on the Indication of the Variometer

A very obvious fact is widely unknown, unfortunately, and this lack of knowledge again and again leads to wrong ideas about total energy compensation. When pulling up at not too small a load factor (normal acceleration) quite generally the total energy variometer's reading goes down at first, whereas the altitude variometer used in the good old times of slow sailplanes (non-compensated variometer) would happily go to the positive end stop on this occasion. Normally one would expect the TE-vario not to move at all. This quite disturbing phenomenon time and again is being regarded as an error of TE-compensation: nothing is more wrong than this. Quite to the contrary, if it does *not* occur then the compensation is not worth much.

When pulling up at an increased load factor the lift of the wing has to carry not only the weight of the glider, but on top of that it has to deliver the force necessary to accelerate the plane's mass upward. The lift then becomes n x W, where n is the load factor and W the weight of the plane (the pressure the pilot feels against the seat accordingly becomes n times that which he feels in straight and level flight). Now, increased lift also will lead to increased drag and this the more the slower one flies, due to the induced drag. The additional drag will consume additional energy. The correspondingly increased energy loss rate can only be fed from the plane's stored potential energy, this having the nasty consequence that the plane will sink faster or climb slower than it would have done without the acceleration. A total energy variometer must register this additional energy loss.

NOTE: a TE-variometer does not indicate vertical speed, but the *rate of change* of the plane's total energy per unit of weight, therefore its name: it measures the variation of the plane's total energy, which is the sum of potential energy (proportional to altitude) and kinetic energy (proportional to the square of velocity). Its indication can be regarded as being equal to true vertical speed *only* in the case where kinetic energy does not change; in other words, where the absolute value of velocity remains constant. Contrary to that, a non-compensated variometer will measure the rate of change of of potential energy alone, which means the rate of change of altitude, or true vertical speed, independent of whether the glider's velocity changes or not. Conclusion: the two types of variometer do indicate the same only when the plane's velocity does not change!

To illustrate that: If we have our plane shoot up on a straight trajectory, ascending at an angle of 15° at a speed of 150 km/h or 82 knots, we will climb at a vertical speed of more than 10 m/s or 20 knots. This rate of climb will be indicated by the altitude variometer, whereas the TE-vario will indicate the actual rate of sink corresponding to the (decreasing) actual velocity, and according to the plane's polar—2 m/s, for instance, at 150 km/h in calm air. However, in a steady circle the two varios will indicate the same, as absolute velocity remains constant; only its *direction* changes.

The effect of acceleration also is present when spiraling: the plane has to be constantly accelerated toward the circle's center (the direction of velocity is being changed constantly). The additional force required for that demands additional lift, which generates more drag, which increases the energy loss rate of the plane and thus the sink rate. Every glider pilot knows this effect, and takes it into account when spiraling in a thermal.

When pulling up the same phenomenon occurs, but its effect on sink rate is not directly evident as in the case of spiraling. This is so because the effect is swamped by the large true vertical speed, the latter being caused by the inclination of the trajectory, and being much greater than the plane's proper sink rate. However, the energy loss is there.

Due to this state of affairs the effect of normal acceleration during the pull-up maneuver will not be discernable on the altitude variometer. However, it is to be seen on the TE-vario quite easily—if it is well compensated—because the part of vertical speed which is due to the trajectory's inclination is compensated out, and only the part due to the energy loss caused by drag is indicated. During actual pulling where the load factor is high the additional loss can lead to an additional sink rate which exceeds the plane's polar sink rate by an important amount. Therefore it becomes clearly visible on the TE-variometer.

Conditions are reversed in a push-over maneuver. As long as the aircraft remains on a trajectory curved downwards it will be accelerated toward the ground, it quasi falls down, and the load factor therefore becomes smaller than 1. Lift is reduced and with it drag, and consequently the energy loss rate is reduced. The sink rate indicated by the TE-vario decreases as the plane follows its curved trajectory. It can approach zero in the case where one follows a parabolic trajectory at near-zero g at low speed, calm air being assumed. As soon as one releases forward pressure on the stick and continues on a straight trajectory—whether inclined or not is of no importance—the effect disappears.

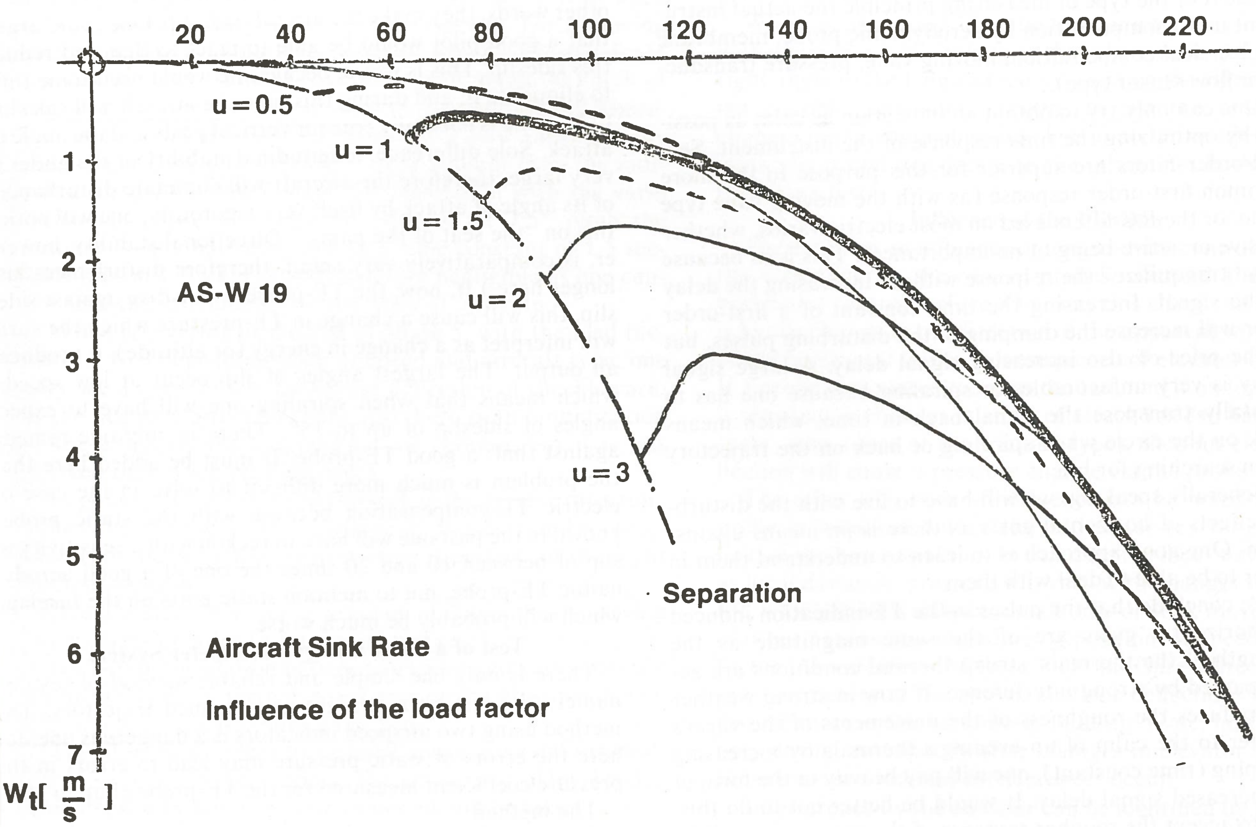
As an aircraft will suffer drag as long as it flies, drag meaning a permanent yet more or less important energy loss, an ideal TE-vario may never indicate climb in still air whatever maneuver one may carry out! Real varios will deviate from this rule, the question of how much being a good criterion for the quality of the system.

The impact of normal acceleration, or load factor, on the sink rate of the AS-W 19 is shown in the accompanying **Figure 1**. For other gliders the curves will show essentially the same shape. The solid curve with $n = 1$ is the normal polar without acceleration. One sees that:

- The normal sink rate will double when pulling up at 1.5 g at a speed of 80 km/h or 44 knots (or when flying a circle at 48° angle of bank at the same speed). Upon pulling even more the flow around the wing will separate and the plane will go into a dynamic stall.
- Pulling to a load factor of 3 at a speed of 110 km/h or 61 knots will multiply the sink rate by a factor of 4!
- At 220 km/h or 122 knots one can pull as much as one can stand; this will have nearly no influence on sink rate and TE-indication.
- At 70 km/h or 39 knots one can reduce the sink rate by one-half by pushing over to 0.5 g, but unfortunately only for a short while!

As we see from all that, total energy compensation does not absolutely eliminate the effects of pulling and pushing, as is said quite often. To the contrary, it really shows the accompanying energy losses! What it eliminates is only the vertical component of velocity due to the inclination of the trajectory (or the effects of the exchange between kinetic and potential energy as a consequence of the inclination of the trajectory).

This state of affairs should be kept in mind when indulging in accentuated dolphin-flying or following the speed command. One should not attribute the sometimes-powerful neg-



ative excursions of the TE-vario to a poor TE compensation, but to one's own maybe too-rough style of piloting. The TE-vario should be well-compensated, however, and not only for this reason.

The Role of Turbulence

As we have seen above, our TE-vario measures the rate of change of the total energy of the plane. The pilot normally thinks in terms of gain or loss in altitude, as it happens for instance in a thermal or an area of sink. Unfortunately, there is another kind of influence on total energy imposed by the atmosphere, namely the gain or loss of kinetic energy by a sudden increase or decrease of the aircraft's velocity with reference to the air caused by horizontal gusts or wind shear.

Every pilot knows this effect, and also knows that after the impact of such a gust he can either pull up to gain some altitude, or he has to push over to regain the speed just lost. In the process he either gains or loses altitude, which means energy. If, now, one observes one's TE-vario carefully one will notice that it makes a jump up or down when passing such a discontinuity. It will not do much during the following maneuver induced by the pilot's reaction on the controls. This sequence of events is perfectly normal, as total energy has changed upon passing the gust or zone of wind shear—by a change in velocity—and as during the subsequent maneuver only potential energy has been exchanged with kinetic energy, leaving the sum constant. (On the altitude variometer, on the contrary, one would see nothing during the first part, but quite a lot during the pilot-induced maneuver.)

It thus remains clear that for a jump in the velocity of the aircraft there is a corresponding jump in its total energy. This jump in energy is "seen" by the TE-variometer exactly the same way as if the glider had made an equivalent jump in altitude at constant velocity, because the vario cannon discriminate by its very principle between the two sorts of energy change. Expressed in mathematical terms this jump is

$$dH = 1/g \text{ times } v \text{ times } dv$$

where g is the earth gravitation constant of 9.81 m/s/s, v is the momentary velocity and dv is the velocity jump (velocities to be inserted in m/s). We observe that the jump registered is proportional to flight velocity. This means that the same jump in wind speed at 180 km/h creates an indicator excursion twice as big as at 90 km/h.

How large are these disturbances in reality? In order to answer this question we have first to determine the magnitude of the disturbances of velocity. There are good physical reasons to suppose that the horizontal component of turbulence is of the same order as the vertical component. (All this has to be seen statistically.) For the latter we would have to take the force of the up or down movements of the air. This means we will have to account for peak horizontal gust velocities of 5 m/s in a meteorological condition giving peak thermals of 5 m/s, for instance. (It does not make much sense to try to read these jumps on the airspeed indicator, as this instrument will generally be too slow for the purpose.)

If, now, we assume a horizontal speed of 150 km/h or 83 knots and use the formula above we arrive at the most astonishing value of ±20 meters for a ±5 m/s gust! Now, depending on its speed of response, the vario will make a large but short, or a smaller but longer bounce. A moving vane vario—one with a time constant of 3 seconds—will jump to about 7 m/s and then descend to its original indication in about 6 seconds (an altitude vario would not have done much here!).

This phenomenon is a basic property of TE-compensation;

there is absolutely no remedy against it! It is absolutely independent of the type of measuring principle the actual instrument uses (compensation by aerodynamic probe, membrane or electrical compensation; moving vane, pressure transducer or flow sensor type).

One can only try to obtain an indication as calm as possible by optimizing the time response of the instrument. Second-order filters are superior for this purpose to the more common first-order response (as with the moving vane type vario, or the RC filters used on most electric varios, whether passive or active being of no importance). This is so because they "tranquilize" the response without increasing the delay of the signal. Increasing the time constant of a first-order filter will increase the damping of the disturbing pulses, but at the price of also increasing signal delay. A large signal delay is very unfavorable for spiraling because one has to mentally transpose the signal back in time, which means back on the circle when spiraling or back on the trajectory when searching for lift.

Generally speaking, we will have to live with the disturbing effects of horizontal gusts as there is no means against them. One good approach is to learn to understand them in order to be able to deal with them.

We conclude that the pulses in the TE-indication induced by horizontal gusts are of the same magnitude as the strength of the thermals: strong thermal conditions are accompanied by strong interference. If now in strong weather one reduces the roughness of the movements of the vario's pointer to the calm of an evening's thermals by increasing damping (time constant), one will pay heavily in the form of an increased signal delay. It would be better not to do this, and to accept the rougher response of the vario as an indication of rougher thermals. In these conditions one will also not react on the controls as calmly as on a quiet evening.

In fact it is easy to distinguish between a jump in airspeed and penetration into an up or downdraft: in the first case one will not notice much of a change in vertical acceleration, but in the second case it will be quite noticeable. However, in everyday soaring life the two events are coupled quite often. This has its problems, but its advantages also: not every pulse caused by a horizontal gust is only that, quite often it marks the beginning or end of a thermal. This might be the reason why most glider pilots have not yet noticed the difference. The pilot who flies often in the mountains will certainly have noticed the phenomenon, for here one often finds quite significant wind shear.

When spiraling over flat terrain one will notice in about 90% of all thermals, if one observes closely, that the TE-vario shows two maxima and two minima for every circle flown. One needs a reasonably fast vario for this. An instrument calmed down by capillaries or the like may calm the pilot, but it will hide the real state of affairs from him. The "fast" competitor will know better, will center thermals better and will therefore climb harder.

One could think that this indication is the real vertical speed, but this is not the case: an altitude variometer which is hooked up to cabin pressure will normally show a much more uniform rate of climb. The reason for that is not the vario itself, but TE-compensation. The TE-vario is influenced by the horizontal component of the thermal's airflow pattern, and the latter obviously has two periods per circle flown.

Horizontal turbulence has another disagreeable influence on the output of the variometer: sudden movements of the air perpendicular to the aircraft's direction of flight will tilt the airstream's angle of incidence in the horizontal plane, or in other words, they make the aircraft sideslip. One could argue that a good pilot would be able to react to that and reduce this sideslip. This is wrong because he would need some time to eliminate it, and during this time the aircraft will sideslip. (The same is naturally true for vertical gusts and the angle of attack. Sole difference: longitudinal stability of the glider is very large, therefore the aircraft will eliminate disturbances of its angle of attack by itself very vigorously; one will notice this on "the seat of the pants." Directional stability, however, is comparatively very small, therefore disturbances last longer here.) If, now, the TE-probe is sensitive against sideslip, this will cause a change in TE-pressure which the vario will interpret as a change in energy (or altitude): it produces an output. The largest angles of slip occur at low speeds, which means that when spiraling one will have to expect angles of sideslip of up to 15°. There is only one remedy against that: a good TE-probe. It must be added here that the problem is much more difficult to solve in the case of electric TE-compensation because with the static probes known in the past one will have to reckon with a sensitivity to slip of between 10 and 20 times the one of a good aerodynamic TE-probe, not to mention static ports on the fuselage which will probably be much worse.

Test of a Total Energy Variometer System

There is only one simple and reliable method of testing, namely the test on a straight and inclined trajectory. The method using two airspeed indicators is a dangerous one, for here the errors of static pressure may lead to errors in the pressure coefficient measured for the TE-probe of up to 50%.

The method:

1. Use only calm air (early morning).
2. Keep airspeed of minimum sink, or minimum speed + 10 km/h, for 10 seconds.
3. Push steadily until reaching a 10 to 15° nose-down attitude, g-meter to read 0.5 to 0.2 during the maneuver, dust to remain down on the floor of the cockpit.
4. Maintain pitch angle by observing horizon or artificial horizon and by gradually acting on the stick.
5. Pull up before reaching V_{NE} and this time bring the plane to a 10 to 15° nose-up attitude.
6. Maintain pitch angle until reaching minimum airspeed.

Observations:

During phase 2 the vario must indicate the minimum sink rate.

While pushing over, phase 3, the vario must climb to near zero because of the load factor being smaller than 1. In the case where the TE-pressure, or the static pressure for electric compensation, are taken from a position far aft of the center of gravity—for example, on the tail fin—the positive excursion of the vario is increased by the effect of the longitudinal column of air between the probe and the vario. This latter effect becomes stronger with the length of the air column and with the change in pitch angle. The effect of the air column is rarely stronger than about 0.5 m/s, meaning that the total reading should not exceed about that value.

Damping of the vario's response leads to a reduction of the pointer's movement, with the penalty that the duration becomes longer. Thus, one will hardly discern the effect with a moving vane type vario, but with the one-second response of an ILEC vario one will clearly remark it, though it will die out more rapidly than with a slow vario.

In phase 4 airspeed will increase linearly with time. A well-compensated vario must indicate the proper sink rate corresponding to the actual airspeed indicated. One must take into account, however, that the vario signal is delayed by the time constant of the vario's response. For a moving vane vario this is about three seconds, which corresponds (in the case of a 15° slope) to an advance of about 30 km/h of the airspeed signal with reference to the vario signal! Therefore one should choose a flat slope for a slow vario. At any rate, one will have to subtract a fixed amount from the indicated airspeed in one's mind for correlation with the vario signal (in phase 5 it must be added). At 7.5° pitch the amount is only half that, and at a time constant of 1.5 seconds it is only 7.5 km/h and therefore negligible as one cannot read the instrument this precisely at any rate.

When recovering at the end of phase 5, with the load factor at 2 to 3 depending upon airspeed and aircraft type, one may see a more or less important deflection of the TE-vario in the negative direction (here also there is an amplification of the effect by the longitudinal air column, but it is less marked than when pushing over).

In phase 6 the polar is run through in the reverse direction. When the average of the readings in phases 4 and 6 corresponds to the polar the compensation is perfect for the flight without sideslip.

One should carry out a number of flights with varying pitch angles in order to get a good picture.

For better correlation between airspeed and vario one can, for instance, mark the polar sink rate on the glass window of the airspeed indicator with a felt pen.

The numerical values mentioned above are valid for modern high-performance gliders. For trainers or older wooden sailplanes, somewhat smaller values should be taken.

Testing the Influence of Sideslip on TE Compensation

All methods of compensation suffer from the influence of sideslip, although to different degrees. It is practically impossible in a strong thermal to maintain a zero sideslip angle, without the risk of falling out of the thermal. If the compensation is sensitive to sideslip it will generate disturbances in this case which can span the range from simple nervousness of the indicator to heavy disturbances (see the earlier section on turbulence). Insensitivity to sideslip, therefore, is an important criterion for good compensation. (According to H. Reichmann there are pilots who push the rudder periodically because with certain TE-tubes there appears a short pulse of climb each time this is done!)

A simple method of judging: maintain a sideslip (at a safe altitude) of at least 30° for three seconds the yaw string will stand out sharply to the side. Then terminate the slip steadily without haste by using rudder and aileron, maintaining an undisturbed pitch angle as far as possible. During the maneuver the vario should transition from rather strong sink to the polar sink rate in a steady fashion and without jumps. It should never exceed the polar sink rate in the process.

NOTE: What counts is only the smooth transition, not the absolute value indicated during the slip. The latter depends on the type of glider and the angle of sideslip. Only at the end should the vario indicate the polar sink rate.

Influence of Angle of Attack

As longitudinal stability is very large and the angle of attack therefore remains within narrow limits (in the normal speed range it is about ± 5°), the change in angle of attack, whether as a consequence of turbulence or of intended flight maneuvers, remains a small problem, except where one uses a poor source of static pressure in the case of membrane systems or electric compensation. Unfortunately, poor sources of static pressure are nearly the only kinds found on gliders.

When using a good TE-tube there normally is no problem with angle of attack, as long as the tube is mounted under the right angle to the longitudinal axis and on the right spot. It is not possible with simple means to test the sensitivity to changes in the angle of attack. Fortunately the effect is automatically tested together with the other ones in the inclined trajectory test.

Influence of the Elevator

There can be an influence of longitudinal control inputs on the variometer in the case of probes mounted ahead of the horizontal control surface. One way this effect can be caused is by the change in the direction of the apparent wind in front of the horizontal tail as a consequence of elevator deflection. If a probe is mounted too near the tail, and if on top of that it is sensitive to changes in angle of attack (as can happen with some older tubes of the Venturi type), then an elevator deflection will cause a pressure change via the probe.

The other way such an influence can be noted is when a probe is mounted within the rather far-reaching pressure field of the horizontal tail. In this case the local static, as well as local dynamic, pressure will vary with changes in elevator lift, which itself is a function not only of stick movement but of other parameters including cg position, airspeed and load factor. As variations of these local pressures directly transmit themselves to the probe, elevator deflections can cause disturbances in the variometer reading. Note, however, that only during and shortly after *changes* in elevator setting do these pressure-induced interferences occur.

Interference by the elevator can be identified by the rather strong reactions of the variometer in both directions when successively pulling and pushing on the stick at moderate speeds. In unfavorable cases this can produce readings which are multiples of those which would be expected from the acceleration effect discussed in the first section of this paper.

When pulling and pushing in a rapid sequence the variometer may well deviate downward but not upward above the zero line.

Remedy: put the probe farther ahead of the horizontal tail and use a tube which is less sensitive to the angle of attack. Horizontal tails with a stabilizer require a larger distance than all-flying tails. The nearer the measuring head of the probe is situated to the plane of symmetry of the horizontal tail, the smaller the interference will be! Vertical distances of half the depth of the vertical fin, for instance, are very bad.

TE Probes on the Fuselage

The fuselage creates a very strong pressure field around itself which will seriously disturb any pressure probe in its vicinity. This is already so in clean, straight flight without any sideslip. Conditions become worse when one slips, or in accelerated flight. An estimation of the errors created is quite difficult because the airstream pattern around the fuselage is very complex and, naturally, different for every type of glider. One should take some general precautions: avoid the vicinity of the wing (the farther away the better) because during pull-ups and accelerated flight the wing will simulate vertical speeds which do not exist. The measuring head of the TE-probe should be as far away from the fuselage as possible (rule of thumb: distance = diameter of fuselage at the place where the probe is mounted) in order to reduce the influence of sideslip to a minimum.

There is another very serious danger coming from the turbulent wake of the wing and fuselage: Where the measuring head of the TE-probe is reached by it, the pressure coefficient will change drastically and very rapidly. The consequence is a powerful disturbance of the TE-vario, mostly in the very low speed region. It is not possible to make a general statement on the position of this wake. Rule of thumb: avoid the region between the upper surface of the fuselage and an assumed plane connecting the upper surface of the wing and the trailing edge of the horizontal stabilizer (in the case of a T-tail).

As one can see, there does not remain much space for a good position of the TE-probe on the fuselage. Practically the only one left is about 1 m behind the trailing edge of the wing. One should use positions on the fuselage only after they have been tested thoroughly with positive results.

By contrast, the position in front of the horizontal tail is comparatively without problems.

Further Disturbing Factors

The influence of acceleration, or the load factor, on the proper sink rate of an aircraft is not an error of measurement, as it has a direct influence on the plane's energy balance. We will have to learn to live with it. The same is true for the influence of turbulence.

Contrary to that, the other influences are errors stemming from the complete measurement system itself, errors which could in principle be eliminated by a more nearly perfect (and naturally more complex) measuring system. It can be said with good justification that the more serious errors can be associated with taking the pressure measurements, and these errors can be traced back to aerodynamic phenomena induced by the aircraft itself, or to the tubing and other mechanics of the system.

Many of these pneumatic measuring errors are very difficult to get hold of because they depend on several influences at the same time. Fortunately they are generally weaker disturbances of TE-compensation which one will notice only with a very good system. We will therefore not deal with them here.

Mutual Interference Between Variometers

If more than one variometer or a vario along with another instrument is being supplied from the same TE-pressure or static source, some caution should be used. The varios can interact with each other, or with other instruments, producing responses different from normal. This can be particularly so where large air volumina (flasks or so-called gust filters) are involved in the system. It is quite possible for the initial response of a vario to be reversed in this way. One should avoid, in all circumstances, restrictions of the airflow such as sharp corners or manifolds forming jets, in ducts common to instruments.

One should at any rate first carry out a test flight with one vario only (or the vario alone), then add the other vario or instrument and see whether the response of the first one has changed in any way, and whether the second one functions properly. Only then should further instruments be hooked up and the tests repeated.

Quality of the Compensation

1. There is no perfect compensation.

2. If, during phases 4 and 5 of the test the averaged sink rates stay within a band of ± 20 cm/s of the polar sink rate in the speed range up to 150 km/h, and if the sideslip and the elevator influence tests were satisfactory, one can qualify the compensation as being excellent. With that system one will notice a 1 m/s thermal even during an ascent under 45°, and when spiraling one will have an indication as calm as possible. Not many systems are as good as that.

3. If the deviations are smaller than ±0.5 m/s, and the other tests are not too bad, we can still call the system a good one. One can be very happy with it at low to moderate airspeeds if avoiding too rough a style of piloting.

Estimation of the Effective Pressure Coefficient of a TE-probe

The pressure coefficient of any probe measured in a free stream will be modified on the aircraft by the aerodynamic effects mentioned earlier. Therefore one must talk of system coefficient here, rather than of a probe's coefficient. (When mounting the probe on the tail fin correctly the combined effects are normally smaller than -5%, but on the fuselage they can reach -10% to +20% easily.) This coefficient combined from tube and aircraft can be estimated, and if necessary it can be corrected, within reasonable limits.

If during phase 4 of the test one has too much sink there is undercompensation and the system coefficient is smaller than 1. In the case of too small a sink reading, or even a climb, the system is overcompensated and the system pressure coefficient is greater than 1.

The error of sink rate and the error of the system pressure coefficient are related in the following way: The error of sink rate is approximately equal to true vertical speed multiplied by (1-B), where true vertical speed is the 1 indicated by an uncompensated variometer, and where B is the system pressure coefficient. Example: slope 15° down, airspeed 144 km/h = 40 m/s sink/ This gives a vertical speed of 40 m/s times sin(-15°) = 10.4 m/s = 10.4 m/s sink. A system coefficient of 0.9 (10% undercompensated) will cause an error in variometer reading of -10.4 m/s times (1 - 0.9) = -1 m/s, meaning that the reading will be a sink rate too large by 1 m/s.

Conversely, one can compute the error in the system pressure coefficient on the basis of an estimation of the error in the TE-vario's reading. (In the case above, 144 km/h, -15°, sink rate too large by 1 m/s, one will arrive at a value of B = 0.9.)

It should be added here that the error of the system pressure coefficient ought to be the smaller, the faster a glider is. With a fast ship one will fly not only faster, but on steeper slopes; the error of the variometer will somehow go with the square of speed! The other way around: On a K8 one can place the tube in a spot which is not that favorable, without much hesitation. However, on a 15-Meter racer one should invest a bit more effort.

TE-Compensated vs. Noncompensated Varios

In modern soaring one cannot really do without the TE-variometer for the purpose of looking for a useable thermal and for adjusting speed during the glide phase, as in both cases one does change airspeed quite a bit. A noncompensated vario would always be at the end stops during these exercises. One could use it, but at the expense of keeping airspeed constant – admittedly not a very attractive solution.

Yet there is one situation where the noncompensated vario's quality of not being disturbed by horizontal gusts is a definite advantage: namely, in rough thermals where the horizontal disturbances can be very nasty indeed. Here the noncompensated vario will deliver an astonishingly quiet signal, where a TE-compensated vario may give an output hardly to be interpreted by the pilot. It is worth a trial.

Observing both a noncompensated vario and a compensated one at the same time also can bring some good information: as long as they both show the same climb rate, there is a real thermal. If only the TE-vario shows something and the altitude vario does not move, there is a horizontal gust constant airspeed assumed (this is often the case, as for example during large portions of the glide). When only the altitude vario moves, then the aircraft is changing its velocity.

With a little bit of experience, having both types of vario may well be a bonus. However, their response should not be too different.

One further remark: On many gliders the cabin pressure is a much less disturbed source of static pressure than the various holes in the fuselage.

Improving an Existing System

1. Contrary to a widespread opinion, a poor compensation cannot be improved by additional damping in the duct to the variometer (capillaries and the like). In this way one will generally convert a poor TE-vario into an even poorer averager.

2. The faster the vario, the more clearly errors of compensation will show up, but the better also the compensation will be, where the pneumatic side of the system is in order. This is so because the disturbing effect of signal delay is smaller.

3. Errors must first be sought at the source, which means in practical terms that with tube-compensated systems the tube first should be put in question and its way and place of mounting, as detailed earlier. With electric or membrane compensated systems the static pressure port should be put right. This, it must be mentioned, is rather a tough task.

4. Where a system using a TE-tube is bad, the problems are either with the tube itself (one can see incredible equipment; we have measured coefficients between 0.8 and 1.5 on homebuilts and even on commercial probes!) or with the place where it is mounted, or with the angular position (we have seen errors of some 30°!). All this is assuming that no other manipulations have been done to it: there are people who like to try different bends in the tube! It can also be that a particular tube and its mounting place do not match.

5. As a general rule, tubes in the vicinity of the wing must be avoided (vicinity here meaning nearer than about one chord length) because they will easily enter into some dependence on the wing lift coefficient, meaning also load factor and acceleration. The variometer's reading in this way can easily lead to misjudging the quality of the thermal one is looking for.

6. Leaks and squeezed flexible tubing can have catastrophic consequences.

7. The science of TE-compensation is a very complex business demanding a few years' specific experience and knowledge in various fields of natural science and engineering. Tinkering will therefore invariably lead to failure and frustration.

Addendum on the Role of Turbulence (For the Scientific-Minded Reader)

When spiraling in a thermal with two maxima of TE-indication one can achieve, by knowingly displacing the circle in a particular direction, a state where one has only one maximum and a minimum per circle flown. Generally, however, the average rate of climb will be rather less here than in the symmetrical case. Now, by displacing the circle in a direction which is at right angles to the original displacement, one generally will notice not much of a difference against the original state. The two axes (obviously they must be considered as such) are coupled to wind direction, and the first one is roughly parallel to it.

This experimental finding can be explained by supposing that the thermal consists of two parallel whirls with horizontal axes, the sense of rotation of which is oriented such that an upward movement is created between them. The whole system has to be imagined as being somewhat diffuse.

Such a system is formed by pulling the toroidal whirl—well known from the model for thermals with rotational symmetry—along a horizontal axis to some length. The circular ring will first become oval; later one will arrive at the model described above showing two more or less long parallel whirls.

It sounds reasonable to suppose that circular as well as linear whirl systems coexist to some extent, depending on the local state of the atmosphere and the state of the surface on the ground, this being also compatible with the experimental findings. The venerable model for thermals sporting rotational symmetry, however, does not seem to be much favored by nature.

The reason for that might be that the lower layer of the air, from which our thermal will mostly come at the end, will have a boundary layer with the ground, as soon as there is some wind. This rather thick boundary layer is a layer with wind shear. This again means that the air contained in it is "affected" by rotation. In other words, it has a moment of momentum with an axis perpendicular to wind direction. Now it is known from the theory of flow that when a mass of air is displaced (in this case on the occasion of its ascent subsequent to heating) its moment of momentum is conserved.

Now, a whirl in the form of a pure torus cannot fulfill this condition: its overall moment of momentum is strictly zero. It excludes itself as a possible solution to the problem as soon as there is some wind. This conclusion also is supported by practice: round thermals normally exist only under conditions of low wind over uniform terrain, and they usually have a large diameter. We must deform the torus whirl in order to impose an overall moment of momentum on it, or—even better—break it up into two linear whirls of different lengths or of different strengths. To fulfill the original conditions the stronger or larger one of the two must be found on the lee side of the thermal. The latter condition would also explain why one has to displace against the wind so often, in order not to fall out of the thermal. We herewith have created the above postulated model.

We will certainly have to assume, in order to remain realistic and compatible with the more refined details of flow theory, that the whole structure is not very stationary and that it is in constant transformation. Mixing of the originally ascending air bubble with the surrounding air will take care of forming, at the end, a more symmetrical structure. At the beginning, most certainly, one will have to expect some dancing around each other of the elements constituting the whole system.

NOTA BENE: The model of a thermal with rotational symmetry is possible only under conditions of zero wind in the layer generating the thermal. Under all other conditions more or less linear whirl structures are necessary to ensure conservation of the boundary layer's moment of momentum.

Final remark: The hypothesis formulated here sounds reasonable to the author. To prove or disprove it one will need both more, and more precise, experimental data, and some thorough theoretical work. Both of these are beyond the scope of the author; he therefore suggests the topic as a basis for possible future work by others interested in the field, and disposing of the necessary ways and means.