

TOTAL ENERGY COMPENSATION IN PRACTICE

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FORWARD

Rudolf Brozel and Juergen Schindler founded ILEC in 1981. Rudolf Brozel was the original designer of ILEC variometer systems and total energy probes. Sadly, Rudolph Brozel passed away in 1998.

ILEC instruments and probes are the result of extensive testing over many years. More than 6,000 pilots around the world now use ILEC total energy probes. ILEC variometers are the variometer of choice of many pilots, for both competition and club use. Current ILEC variometers include the SC7 basic variometer, the SB9 backup variometer, and the SN10 flight computer.

INTRODUCTION

The following article is a summary of conclusions drawn from theoretical work over several years, including wind tunnel experiments and in-flight measurements. This research helps to explain the differences between the real response of a total energy variometer and what a soaring pilot would prefer, or the ideal behaviour. This article will help glider pilots better understand the response of the variometer, and also aid in improving an existing system. You will understand the semi-technical information better after you read the following article the second or third time.

THE INFLUENCE OF ACCELERATION ON THE SINK RATE OF A SAILPLANE AND ON THE INDICATION OF THE VARIOMETER.

Astute pilots may have noticed when they perform a normal pull-up manoeuvre, as they might to enter a thermal; the TE (total energy) variometer first indicates a down reading, whereas the non-compensated variometer would rapidly go to the positive stop. One would expect the TE variometer to not move at all. Many pilots interpret this phenomenon as an error of the TE compensation device and proceed to install further devices, or to begin shortening or lengthening tubes and/or tubing in an attempt to trim the system to remove this initial down indication. On the contrary, if your variometer does not show this initial down indication, your total energy compensation is not working properly!

When you perform a pull-up maneuver, additional G forces are produced. The lift of the wing must carry the increased weight of the glider, as during an un-accelerated, steady speed glide, but also must induce the additional force to accelerate the glider upward. The lift becomes $n \times w$ where n is the load factor and w is the weight of the glider. This increased lift also causes increased drag. The additional drag consumes additional energy. The increased energy loss rate can only be fed from the glider's potential energy stored, which causes the glider to sink faster, or climb slower than it would have

without the acceleration. A total energy variometer must register this additional energy loss - therefore the down reading.

A TE variometer doesn't indicate vertical speed. It shows the rate-of-change of the glider's total energy per unit of weight - therefore it's name. It measures the variation of the glider'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 only be regarded as being equal to true vertical speed in the case where kinetic energy does not change, in other words: where the absolute value of velocity (airspeed) remains constant. In contrast, a non-compensated vario will measure the rate of change 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 variometers indicate the same only when the glider's airspeed does not change.

If you have your glider shoot up on a straight trajectory ascending at an angle of fifteen degrees at a speed of 82 knots, you will climb at a vertical speed of more than twenty knots. This rate of climb will be indicated by the non-compensated altitude variometer, whereas the TE variometer will indicate the actual rate of sink corresponding to the actual velocity, and according to the glider's performance polar, for example -4 knots at 82 knots in calm air. In a steady circle at constant airspeed, the TE and uncompensated variometers will have the same indication, as the airspeed does not change even though the direction does.

The effect of acceleration is also present when circling: The glider has to be constantly accelerated towards the circle's center (the velocity direction changing constantly). The additional force required during a turn demands greater lift, which also generates more drag, which increases the energy loss rate of the glider, and thus increases the sink rate. Every glider pilot knows this effect while in curved flight, and takes it into account when circling in a thermal.

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

The effect of acceleration during the pull up manoeuvre will not be discernible on the non-compensated variometer. However, it is easily seen on the TE variometer if it is well compensated, because the part of the vertical speed, which is due to the trajectory's inclination, is compensated out, and the part due to the energy loss caused by the increased drag is still indicated. During actual pulling where the load factor is high, the additional loss can lead to an additional sink rate, which exceeds the glider's polar sink rate by an important amount. Therefore it becomes clearly visible on the TE variometer – the harder you pull, the more the variometer deflects downwards.

Conditions are inverted in a pushover manoeuvre. As long as the aircraft remains on a trajectory curved downwards it will be accelerated towards the ground; it quasi "falls" down and the load factor becomes smaller than one. Lift is reduced and also drag, and consequently the energy loss rate. The sink rate indicated by the TE variometer decreases as the glider follows its curved trajectory. It can approach zero sink rate in the case where one follows a parabolic trajectory near zero 'G'; calm air being assumed.

As an aircraft suffers drag as long as it flies, an ideal TE variometer would never indicate climb in still air no matter what manoeuvre is performed! Real variometers will deviate from this rule; how much is a good criteria for the quality of the TE system.

The effect of normal accelerations (load factors) on the sink rate of an ASW-19 follows. For other gliders, the effect is essentially the same.

- The normal sink rate will double when pulling up at 1.5 G at a speed of 44 kts, or when flying at a 48-degree bank angle at the same speed. Upon pulling even more, the flow around the wing will begin to separate.
- Pulling to a load factor of 3 at a speed of 61 kts will multiply the sink rate by a factor of 4.
- At 122 kts one can pull as much as one can stand: This will have nearly no influence on sink rate and/or TE indication.
- At 39 kts, you can reduce the sink rate by one half by pushing to one half-G. For a short while only, unfortunately.

We see from this discussion that total energy compensation absolutely does not eliminate the effects of pulling and pushing. To the contrary, it really only 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 flight or following the speed command computers. One should not attribute the sometimes-powerful negative excursions of the TE variometer to a poor TE compensation, but to one's own too rough style of piloting. Be gentle on the controls to give more useful variometer readings.

THE ROLE OF TURBULENCE

As we have seen, the TE variometer measures the rate of change of the total energy of the glider. The pilot normally thinks in terms of gain or loss of altitude as it happens in a thermal or downdraft area. Unfortunately there is another kind of influence on total energy imposed by the atmosphere: the gain or loss of kinetic energy by a sudden increase or decrease of the aircraft's velocity with reference to air by horizontal gusts or wind shear.

Every pilot knows this effect and also knows that after such a gust, one can either pull up to gain some altitude, or push over to regain lost speed. In the process, the glider either gains or loses altitude, which means a change of energy. If you watch closely, the TE variometer will jump up or down as the glider passes through such a gust, indicating a gain or loss in the total energy available to the glider.

This jump in "energy" is seen by the variometer exactly the same way as if the glider had made an equivalent jump in altitude at constant velocity. The TE variometer cannot discriminate between the two sorts of energy change. Expressed in mathematical terms, this jump is $dH = 1/G \times V \times dV$ where G is the earth's gravity constant = 9.81 m/s/s, V is the momentary velocity, and dV the velocity jump. We observe that the jump registered is proportional to flight velocity. This means that the jump in wind speed at 120 kts creates an indicator excursion twice as big as at 60 kts.

How large are these disturbances in reality? In order to answer this question we have to determine the magnitude of the disturbances of velocity. There are good physical reasons to suppose the horizontal component of turbulence is of the same order as the vertical component. This means we will have to consider typical horizontal gusts as much as 10 knots.

If we assume a horizontal airspeed of 83 knots and use the formula above, we arrive at the most astonishing value of +/- 60 feet for a +/- 10-knot gust. Depending on its response speed, the variometer will make a large but short duration, or a smaller but longer duration bounce. A moving vane variometer with a time constant of 3 seconds will jump about 15 feet per minute and then descend to its original indication in about six seconds.

This phenomenon is a basic property of TE compensation. There is no remedy against it. It is absolutely independent of the type of measuring principle the instrument uses (compensation by aerodynamic probe, membrane, electrical compensation, moving vane, pressure transducer, or flow sensor types).

One can only try to obtain an indication as calm as possible by optimising the time response of the instrument. Variometers with second order gust filters introduced by ILEC are superior for this purpose to the more common first order filters. This is so because second order filters "tranquelize" the response without increasing the delay of the signal as do first order filters.

In fact, it is fairly easy to distinguish between the variometer's responses to horizontal gusts vs. a real thermal. In the first case, one would not notice any vertical acceleration (G force) but in the other quite easily. Of course, in the real world, the two events are often coupled together. Not every pulse caused by a horizontal gust is only that. Quite often, it is the first indication of a real thermal. This is probably the reason most pilots have not noticed the phenomenon.

A horizontal gust acting perpendicular to the aircraft's flight can be seen when the yaw string is deflected. If the TE probe is sensitive to these side gusts, the variometer will indicate a change in energy. The problem is much more difficult in the case of electronic total energy due to the gust sensitivity of the glider's static ports. During thermalling, side-slip angles of up to 15 degrees are not uncommon (because of air circulation in the thermal, not pilotage). Therefore, a good TE probe will give much better results than electronic compensation.

TESTING A TOTAL ENERGY SYSTEM

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

The method:

Use calm air (early morning). You will not get clear results testing while thermals are active.

Step 1: Fly the airspeed of minimum sink, or minimum speed plus 5 kts for at least ten seconds.

Step 2: Push steadily until reaching a 10 to 15 degree nose down attitude. The G-meter should indicate .5 to .2 G. Dust should remain on the floor of the cockpit.

Step 3: Maintain pitch angle by observing horizon and with gentle stick motion.

Step 4: Pull back before reaching V_{ne} , and bring the nose to 10 to 15 degree nose up attitude.

Step 5: Maintain pitch angle until reaching minimum speed.

Observations:

Step 1: The variometer must indicate the aircraft's actual minimum sink rate.

Step 2: During the push-over, the vario must climb to near zero because of the load factor being smaller than one. If your TE probe is far aft of the centre of gravity, (on the tail or fin) the positive excursion of the vario is increased by the effect of the longitudinal air column between variometer instrument and the probe. 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 1 kt, meaning that the total reading should not exceed about +1 kt.

A damped vario has a smaller pointer movement, but it moves for a longer time. Thus, one can hardly see this effect with a slow mechanical variometer, but it is clearly visible with an ILEC variometer.

Step 3: The airspeed will increase linearly with time. A well-compensated variometer will indicate the proper sink rate corresponding to the actual airspeed indicated. However, the variometer signal is delayed by the time constant of the variometer's response. For a moving vane type variometer, this is about 3 seconds (or a 15 knot airspeed lag for a 15 degree pitch angle).

Step 4: During the pull-up with a load factor of 2G or 3G, you will typically see a deflection of the T.E. variometer in the negative direction. During this time, there is an amplification of the effect by the longitudinal air column in the T.E. tubing to the tail.

Step 5: As you decelerate, the glider's polar is run through in the reverse order.

When the average of the readings of step 4 and 6 corresponds to the actual polar the compensation is perfect. One should carry out a number of flights to get a good picture of the compensation.

TESTING THE INFLUENCE OF SIDESLIP ON T.E. COMPENSATION

All methods of compensation suffer from the influence of sideslip. It is practically impossible, in a strong thermal, to maintain a zero sideslip angle, due to air circulation in the thermal. If the compensation is sensitive to sideslip, then it will generate

disturbances in the variometer reading. Insensitivity to sideslip is thus an important criterion for good compensation.

The largest angles of turbulence-induced sideslip occur at slow speeds as in thermalling. You can expect these turbulence-induced slips as great as fifteen degrees! Only the best TE probes can handle this. It must be added that the problem is much more difficult to solve in the case of electronic TE compensation because of the sensitivity to slip is greater than a good aerodynamic probe.

It should be noted, the glider's pitch stability is very strong, and the glider will vigorously eliminate disturbances to its angle of attack. Yaw stability, however, is comparatively very small; therefore disturbances last longer and affect the glider more.

A simple method of testing is to maintain a sideslip (at altitude) of 30 degrees for three seconds. Use the yaw string as an indicator. Straighten the sideslip without haste using rudder and aileron, maintaining pitch attitude as far as possible. The variometer should transit from rather strong sink to the polar sink rate in a steady fashion without jumps. It should never show less sink than expected from the polar.

What counts is only the smooth transition, not the absolute value indicated during the slip. Only at the end should the vario indicate the polar sink rate.

INFLUENCE OF ANGLE OF ATTACK

Longitudinal stability is very great, and angle of attack therefore remains constant within reasonable limits (in the normal speed range +/- 5 degrees). The change of angle of attack due to turbulence or intended flight manoeuvres is only a small problem except when one uses a poor source of static pressure in the case of membrane systems or electronic compensation. Unfortunately there are at best only poor sources of static pressure.

When using a good TE probe there is normally no problem with angle of attack, as long as the probe is mounted at right angles to the longitudinal axis of the glider, and at a correct location. TE probes are best mounted high on the vertical stabilizer parallel to the aft fuselage cone.

INFLUENCE OF THE ELEVATOR

Pitch control inputs can influence the variometer in cases where the probe is mounted ahead of the elevator. Note that this effect is only during or shortly after the elevator is moved.

One way a pitch input affects the variometer is because the probe sees a change in relative wind. If the probe is very sensitive to angle of attack changes such as the older venturi type probes, then moving the elevator will cause a pressure change via the probe.

The pressure field in front of the horizontal tail plane is rather far reaching. The local static as well as dynamic pressures will vary with elevator deflections. Centre of Gravity position, airspeed, and load factors also influence the pressure field forward of the horizontal tail plane. Note that only during, and shortly after a change in elevator setting

do these interferences occur. If the probe is too short, these local pressure changes will result in variometer motion when the elevator is moved.

You can test interference by the elevator by rather strong reactions of the variometer in both directions when successively pulling or pushing at moderate speeds. When pulling and pushing in a rapid sequence, the variometer may well deviate downwards but not upwards over the zero line.

The remedy for these problems is to mount the probe further ahead of the horizontal tail plane with a longer probe that is less sensitive to angle of attack. The head of the probe should be as close as possible to the plane of symmetry of the horizontal tail plane. The smaller the vertical offset, the less the elevator affects the variometer. A vertical distance over half the depth of the horizontal tail plane is 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 even so in clean straight flight without any sideslip. Conditions become even worse during sideslips or accelerated flight. An estimation of errors created is quite difficult because the air stream pattern around the fuselage is very complex and naturally different for every type of glider. Some general precautions:

Avoid the area near the wing. The further away, the better.

The measuring head of the probe should be as far away from the fuselage as possible. As a general rule of thumb, at least a full diameter of the fuselage at the mounting point.

Avoid the region between the wing and a projected line to the trailing edge of the horizontal tail plane (in the case of a T tail). At low speeds, this region is very turbulent and will affect a probe severely.

As you can see, there remains very little space for a good position of the TE probe on the fuselage. By contrast, the position on the fin in front of the horizontal tail is comparatively without problems.

FURTHER DISTURBING FACTORS

The influence of load factors and turbulence on the proper sink rate of a glider is something we can do nothing about. We will have to learn to live with them.

The other influences are errors stemming from the complete measuring system proper; errors which could be eliminated by a more perfect system, however more complex. It can be said with good justification that the more serious errors can be attributed to taking the measuring pressures, and here with they can be traced back to aerodynamic phenomena induced by the aircraft itself, and to the tubing.

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 the TE compensation, which one will only notice with a very perfect system.

MUTUAL INTERFERENCE BETWEEN VARIOMETERS

If more than one variometer is being supplied with the same TE probe or static source, some caution should be applied as the variometers can interact with each other. This is particularly true when large flasks or so-called "gust filters" are used. In the worst case the initial indication of the variometer can be reversed! Generally, two variometers should be connected to the T.E. probe as far away from each other as possible. Placing a T in the TE line under the pilot seat and running separate lines forward to each variometer can help greatly.

When using multiple variometers, perform a test flight with only one variometer connected. If the response is correct, connect the second variometer and repeat the test. If the response of the first variometer is affected, correct the plumbing !

ILEC variometers normally do not disturb other variometers, due to their tiny flasks (only .45 liter volume). However, an ILEC variometer can easily be disturbed by another instrument.

COMPENSATION QUALITY - SUMMARY

1. There is no perfect compensation.
2. If (during steps 3 and 5 of the above test) the averaged sink rates stay within +/- .2 m/s (+/- .4 knot) of the polar sink rate in the speed range up to 100 knots, and if there is no excessive indication during pitch inputs or side-slip, one can qualify the compensation as excellent. With this system, one can easily see a 2 knot thermal even during a 45 degree pull-up, and when thermalling one will have minimal extraneous variometer indications.

If the average sink rates stay within +/- .5 m/s (+/- 1 knot), the compensation should be considered good.

IMPROVING AN EXISTING SYSTEM

Contrary to widespread opinion, a poor compensation can not be improved by additional damping (capillaries and the like.) In this way, one will generally convert a poor T.E vario into an even poorer averager.

The faster the vario, the clearer the errors of compensation will show. While some manufacturers promise faster variometers, in practice this has repeatedly been shown to be counter-productive.

Errors must first be sought at the source. This means with the tube or the way it is mounted. With electronic TE compensation, the static system must be completely free of errors, which as we see above is very difficult.

Leaks, too-flexible tubing, or squeezed flexible tubing are the most frequent causes of poor TE compensation when using a good quality TE probe.

Leaks and pinched tubing can have catastrophic consequences.

The probe must be mounted correctly. Don't mount a TE probe near the wing, as anything within one chord-length from the wing will be affected by the changing wing C_L (load factor or acceleration). The axis of the TE probe should be aligned with the relative wind at around max L/D speed.

If a system using a TE probe works improperly, and is free from leaks, isolated from other variometers, and mounted in the correct location, then the problem is likely with the tube itself. We have seen many different attempts at manufacturing a TE probe, and also many probes that have been „adjusted“. For good results, use high-quality probe !