Effects of horizontal gusts on Total Energy variometers

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Ever overcooked a final glide after a low scrape and flown home at 120 + knots only to see the vario indicate 10 knot thermals everywhere?

Ever flown on a day when your vario tells you that there are 5 knot thermals and when you turn into them you find 7 knot sink? You probably put it down to turning the wrong way.

Considerable effort and thought has been expended on gadgets to tell you which way to turn, from thermistors and/or humidity sensors on the wingtips to wing bending sensors. All of these devices have problems which have prevented them from working at all or being widely adopted.

In fact the fundamental flaw in the concept of thermal detectors is that there may be no thermal (vertical air motion) at all when the vario indicates climb.

Here's what is going on.

Most variometers in modern sailplanes are Total Energy compensated in order to remove the effects of the pilot pulling and pushing on the stick. This would otherwise cause vario indications due to the glider rising and sinking as it is slowing and speeding up. These will mask the effects of changes in the air in the thermal you are trying to use.

The Total Energy compensation device is usually a pressure source which acts like a venturi even though it nowadays doesn't look like one.

It can be shown that the TE device must produce a pressure below the static pressure by the same amount that a pitot will be above static pressure at the same airspeed.

In flight the pressure at the TE Probe is the sum of the static pressure and the suction produced due to airspeed. At constant airspeed the TE probe acts like a static source and the variometer indicates the rate of change of static pressure converted to equivalent rate of climb or sink.

Note that the pressure seen by the vario changes with airspeed.

When we fly in a convective atmosphere there are all scales of turbulence from the very small (sound waves, basically) to thousands of kilometers in extent(synoptic meteorology) with all the scales in between.

Given that we know air goes up and down in the convective layer at 5 to 10 knots typically and that there is mixing at the edges of thermals and general turbulence in a convective atmosphere it is not surprising that as you fly through a given piece of air the air may not be everywhere moving horizontally at constant velocity.

The glider has very low drag in the direction of flight so takes a long time to actually slow or speed up due to these horizontal gusts and may fly from one parcel moving in one direction to another moving in another direction before it has done so.

This causes airspeed fluctuations which are relatively small most of the time (a few knots at most) and are unimportant to the pilot as far as airspeed control is concerned. A moments thought will reveal that airspeed changes will cause suction changes at the TE probe and hence a reading on the variometer. What is surprising is the magnitude of the effect.

If the air encountered by the glider has region where over a distance of a couple of hundred meters the horizontal gradient of the wind is +1 m/s per 100m a glider flying at 50 knots (approx 25m/s) will cover the 100m in 4 seconds and see it's airspeed increase by 1 m/s or about 2 knots.

The 1 m/s in four second change in airspeed is the same as that seen when you push the stick forward and change the flightpath gradient by 1 in 40 or about 1.5 degrees (point the glider straight down and the airspeed will increase at nearly 10m/s per second or 20 knots/sec - the rest is simple trigonometry). This is a small change but results in an additional sink rate of 0.625 m/s or 1.25 knots approximately.

In the horizontal gust case the glider where isn't actually sinking but continuing on its original flight path, the vario will show at 50 knots TAS a climb of 1.25 knots when encountering the gust in the example.

So far so good. Hopefully we are looking for lift better than 1.25 knots when the glider encounters such gusts. On very poor days when 1.25 knots is acceptable the air is usually less gusty. In your 1-26 or K8 you don't have much of a problem as you wouldn't fly much faster than this.

Now look at the case of the SAME AIR being flown through at 100 knots or 50 m/s. The airspeed change is now 2 knots in 2 seconds or 0.5m/s per second and to get this acceleration in a pushover we would need to change the flightpath gradient by 1 in 20. This causes an additional sink of 2.5 m/s or 5 knots which isn't there in the gust case and so the vario reads 5 knots climb. Now we have a problem - the reading is comparable to the lift we might like to turn in and if we only look at the vario we might want to turn. What we will find is that after 180 degrees of turn we are going through the gust the other way and it causes the vario to read sink. Note that there has been NO vertical air motion here and you have wasted 30 seconds or so doing the turn and are lower than you started in the same place horizontally - maybe 100 feet or so lower in energy terms, which if the average rate of climb in the next thermal is 3 knots, costs you another 20 seconds.

The effect of the gust depends on the horizontal gradient in the air and for any given gradient causes a vario reading proportional to the SQUARE of the TRUE AIR SPEED.

Now in a modern glider 85 knots indicated or so isn't a very high cruising speed and at around 10000 feet this is close to 100 Kts TAS. You can calculate what happens at higher TAS.

Not only are the vario signals due to horizontal gusts comparable in size to the ones we are looking for due to vertical air motion but the durations are too. Slowing the vario causes you to lose information about vertical air motion too.

With current technology the only way to tell is to feel the vertical acceleration due to vertical air motion and mentally correlate this with the vario reading. If you get a vario reading with no vertical acceleration it's a horizontal gust. It's much easier to learn this with a properly compensated TE vario with reasonably fast response so that the vario doesn't have instrument or installation induced errors and the vario and "seat of your pants" are in phase.

How bad is the problem in reality? We did a test flight in a Nimbus 3DM on a day that wasn't particularly gusty. Over sample periods of 2 minutes while flying at 80 knots approximately we found that total energy variometer excursions lasting from 0.5 to 2 secs or more would occur at least every 10 to 15 seconds. The shorter lasting gusts caused large excursions of 6 to 8 knots but these were damped by the slowed variometer response. Even the longer lasting gusts caused significant excursions of 2 to 4 knots. The damped TE vario response showed a significant lag over the undamped vario introducing a delay into detection of real vertical air motion while still showing the effects of the horizontal gusts.

I believe this is why some people find initial cross country flights difficult. You learn to fly floating around the airfield at 50 knots. Catching thermals on the run from 70 or 80 knots IAS is more difficult even if the vario system is working properly. The ability to distinguish between real thermals and vario readings caused by horizontal gust encounters is essential for modern soaring pilots. It is a problem that has crept up on us as gliders of better performance have begun to be able to cruise at higher speeds and variometers of fast response connected to accurate TE probes have come into use.

It is also a reason for using the "constant attitude" method of inter-thermal cruise through "thermals" you aren't going to circle in. If you are enthusiastically dolphining the changing G loads will mask the G loads due to real vertical air motion. There are other effects in TE vario systems due to changing G loads that cause them to work much better when you make smooth and gradual attitude changes. You might also not make yourself sick and you have more time to look around and actually see that steeply banked circling glider going up through your horizon.