Variometer pneumatics – probes, tubing, restrictors, etc.

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Confusion and mis-information about glider pneumatics is widespread in the gliding community. This is a short trip through the science plus simple recommendations for CNv users and sales representatives

Part 1. -- Some Theory

A. Glider mechanical airspeed indicator (ASI) connections.

The pitot port, typically located in the fuselage nose but sometimes on the vertical fin, faces forward and senses Total Pressure (P Total). The ASI static ports are typically located on the port and starboard side of the forward fuselage. These ports are joined to create a Static Pressure that is more or less independent of both airspeed and glider yaw. The ASI senses Dynamic Pressure = Total Pressure – Static Pressure. Kinetic energy is proportional to Dynamic Pressure while indicated airspeed (IAS) is proportional to the square root of Dynamic Pressure.

Most modern gliders have additional Static Pressure ports on the aft fuselage. These are less sensitive to airspeed, and therefore more accurate than the forward fuselage static ports. However, in a glider that carries water ballast, there is a danger that dumped ballast water "drowns the aft statics", causing IAS errors. The reliable but less accurate forward static ports are used by the glider manufacturers to measure safety-related airspeeds such as Stall Speed and VNE (Velocity Not to Exceed).

Good instrument practice is to use the ASI ports for the mechanical ASI only. However, it is common and harmless to use the ASI Total Pressure (pitot) port for electronic instruments. Because the forward statics are less accurate than aft or multi-probe statics, they are not recommended for electronic instruments that compute wind speed and direction.

B. Glider pneumatic tubing.

Pilots sometime question the role of tubing in variometer performance.

Q. Is there significant pressure signal delay in the tubing between vertical fin and the instrument panel? One can reasonably suggest that the difference in tubing length between a nose pitot port and and aft fuselage ports would create false airspeed signals in turbulent air.

A. Theory and the author's measurements show that signal delay in 10 meters of typical glider tubing is less than 0.1 seconds. In practice this is completely insignificant.

Q. What about the tubing that connects a flow-based variometer to the required flask?

A. This particular tubing should be Tygon. Use of a long, soft tube can false vario readings when the tubing is bumped or squeezed. A short piece of soft silicone tubing at the instrument is OK.

Short lengths of soft silicone tubing are good for connections between glider tubing and instrument fittings. They don't leak or stiffen with age; and unlike Tygon, they are easy to disconnect for instrument service.

Q. Sometimes it is necessary to connect two instruments to the same source of air pressure. This is done with a "T" or "Y" tubing coupler. Does the location of the coupler or the curvature of the tubing affect instrument performance?

A. No

C. Total Energy Probes and Multi-probes.

Total Energy probes are typically mounted on the vertical fin. The port(s) face backward, so Total Pressure – Static Pressure is a negative quantity. In other words, Dynamic Pressure measured this way is a negative number whose magnitude increases with airspeed. Recall that Dynamic Pressure is linearly related to kinetic energy. The elegant result is that, as the pilot pulls back on the stick, the Static Pressure decrease is matched by the decrease in the magnitude of the negative Dynamic Pressure. In other words, the increase in potential energy (decrease in Static Pressure) is matched by the decrease in negative kinetic energy. Ponder that & smile! A modern glider efficiently translates Kinetic to Potential energy and vice-versa. The result is a single quantity that is neither dynamic nor static pressure, but is invariant to exchanges between potential and kinetic energy induced by the pilot. Connect a TE probe to a pressure gage, compute the rate-of-change, and Voila, you have a Total Energy (TE) variometer.

----- But only to first order. A typical TE probe is more sensitive to Static Pressure change than to negative Dynamic Pressure change. You can imagine the problem created by a single hole on the back side of a round tube. Local airflow around the tube reduces the magnitude of the negative Dynamic Pressure. Most TE probes compensate for 90% to 95% of Kinetic Energy changes. The EAS double TE probe is one exception with experimentally verified 98% compensation over typical glider airspeeds.

--- And another problem. Wing loading and hence induced drag increases during a pull-up. The increased drag bleeds Total Energy; and the TE vario reading will show this. Unless this effect is computed and applied as a vario compensation, a vigorous pull-up will partially mask thermal lift.

Modern glider instruments also sense Dynamic Pressure (Total Pressure – Static Pressure) directly. Thus it is possible to electronically increase the pneumatic TE compensation by the required 5 – 10 %. By the same token, it is both possible and sensible to compute potential energy from Static Pressure and kinetic energy from Dynamic Pressure. Adding the two energies obviously yields total energy, eliminating the need for a separate TE probe. The CNv senses Total Pressure, Static Pressure, and TE probe pressure. This means the pilot can configure the instrument for pneumatic or electronic TE compensation, or any combination of the two.

Recall that signal delays from pressure sensing ports on the glider is less important than pressure accuracy – especially that of the static port(s). This means a nose pitot and aft static port(s) produce a reasonably accurate Dynamic Pressure signal. And, of course, aft fuselage static ports produce an excellent Static Pressure. With self-draining static ports on most modern gliders, problems related to water ballast dumping are significantly reduced.

D. Specialized pitot and static ports.

Gliders built in the last 20 years are often equipped with a specialized fin-mounted probe that incorporates a pitot port, an annular ring of holes compromising a static port, and sometimes a TE port. They are referred to as multi-probes or triple-probes. Multi-probe ports are carefully designed to meet performance goals. Glider angle-of-attack changes with airspeed. Multi-probe pitot port diameter and spherical probe tip are chosen to reduce Total Pressure dependence on angle-of-attack. Near the small, annular Static Pressure ports, the probe surface is roughened to control local turbulence. While not important for safety, these multi-probe features contribute to GPS-based wind accuracy.

D. Probe and pressure sensor location on the glider

In the quest for un-disturbed air, TE probes and multi-probes are mounted high on the glider's vertical fin. The probes are sometimes lengthened to perhaps reduce potential "bow-wake" effects from the vertical fin , and perhaps to keep the ports further above fuselage and wing/fuselage junction vortices.

Using two CAI 302 flight instruments with special software to take high resolution pressure samples at 5 Hz, the author compared TE probe pressures and Dynamic Pressures taken simultaneously from a fin-mounted multi-probe and a multi-probe that extended 1 meter in front of the glider fuselage.

The nose-mounted probe location was selected to completely eliminate turbulence effects on sensed pressures. Over a range of airspeeds, there was no detectable difference in accuracy or 5 Hz "noise" attributable to turbulence between fin-mounted and nose mounted multi-probes. This result strongly suggests that there is no performance advantage to nose-mounted probes.

In a further quest for measurement accuracy, some have suggested locating the pressure sensors in the vertical fin to reduce tubing effects. It has been shown that for, lengths used in gliders, tubing does not cause signal degradation. Also, the pressure sensed depends on the altitude of the sensor, not the port. Therefore, a fin mounted altimeter sensor will be more sensitive to pilot-induced pitch changes than an altimeter mounted on the instrument panel a short distance forward of the pitch axis.

E. Pneumatic control of instrument response

Imagine a long, very thin syringe needle. Air flowing through the needle encounters friction and a pressure drop proportional to its length. Put this "restrictor" in tubing close to an Absolute pressure sensor. Does this significantly increase the response time of the sensor? The answer is – no.

Why? Almost no air flow is required for the sensor to respond to the pressure change.

Now put a flask containing 0.5 liters of air in the tubing between the needle and the pressure sensor. Air must flow through the needle to raise the pressure in the flask. The bigger the flask, the longer this takes. Longer tubing or smaller tubing diameter results in higher resistance to flow. This also increases response time of the pneumatic system. The result is a simple first-order low-pass filter. The electrical analog is a resistor, R, and a capacitor, C. The time constant is $\tau = R*C$.

F. Variometers based on direct pressure measurement

New variometer designs rely on high-resolution sensing of air pressure relative to a perfect vacuum. The devices are known as Absolute Pressure sensors. Direct pressure measurement requires very little airflow since fuselage tubing internal volume is typically less than 0.1liter, and there is no airflow at the sensor itself. Even with the small static and pitot ports on a multi-probe, the sensed pressure time constant is typically less than 0.1 second. This is much faster than required for a variometer. Therefore, modern vario response speed is controlled electronically rather than pneumatically.

G. Variometers based on air flowing into and out of a 0.45 liter flask

Historically, glider variometers were mechanical devices that sense the flow of air into and out of an insulated flask (typically 0.45 Liter capacity). The well-known Winter and PZL variometers consist of a vane that rotates in a cylindrical chamber. A hairspring and balance weights determine the zero position of the vane and associated pointer. The Winter vario has a precision, inclined notch milled into the cylinder cover. The area through which air passes from the TE probe to the flask increases with vane rotation away from zero. As lift increases, more air flows from the flask to the TE probe. The pointer moves until the pressure developed by the moving air is precisely matched to the opposing pressure of the hairspring.

The interesting result is that the airflow resistance is high at low TE climb rate and goes down as lift rate increases. This is the reason why a Winter vario can be very “jittery” in a 5 knot thermal and yet take a very long time to settle to zero lift during ground-based testing.

The Schuemann-Sage vario uses a very sensitive mechanical pressure sensor to measure pressure drop across a long piece of very small-bore tubing. Because airflow in the tubing is laminar, its effective resistance does not change with lift rate, so it maintains its fast response in low lift conditions. However, this vario is so fast that it must be used with a pneumatic restrictor in the line between the TE probe and variometer.

In this special case one need only add the resistance element of the filter; the 0.45 liter flask supplies the necessary volume for response time control.

When driving both a pressure-based variometer and a flow-based variometer with the same TE probe, it may be possible to see artifacts due to the flow-based variometer. For example, an improperly balanced Winter vario vane will respond to vertical acceleration. This, in turn can cause pressure changes on the TE-probe side of the instrument. Reported odd variometer behavior is anecdotal and varied. In general, it is a very bad idea to connect a pressure-based vario to the tubing between a restrictor and a flow-based vario.

Part 2. – Recommendations for CNv users

A. The Clearnav vario is unique in its use of three independent Absolute pressure sensors for measurement of Total (P), Static (S), and Total Energy (TE) pressures. Dynamic Pressure is obtained by electronically subtracting Static from Total pressure. This means you can select either TE probe or Electronic TE compensation without changing connections. Connection of the CNv to a TE probe will never modify the response of another connected vario, even though a flow-based vario may affect the behavior of a CNv configured for probe TE compensation. Therefore, in all configurations where two or more varios are in the cockpit, we recommend connecting the CNv TE sensor directly to the TE probe tubing in front of any restrictors that may affect its response.

As the CNv uses sophisticated software-based pressure sensor filtering, we strongly advise against using pneumatic restrictors between glider pressure ports and the CNv P, S, or TE ports.

B. If your glider has a TE probe, but no multi-probe, we recommend the CNv Static (S) sensor be connected to the aft fuselage static ports. Of course, the CNv Pitot (P) sensor must be connected to any available fuselage Pitot.

C. If you have a motorglider with a multi-probe, and you do not have panel-mounted valves for both pitot and static pressure, we recommend using fuselage ports for Total and Static pressures. We further recommend that you configure the CNv for electronic rather than pneumatic TE compensation. Configuration for motorgliders with panel-mounted valves is obvious.

D. If you have a non-motorized glider, we recommend multi-probe P and S ports for CNv use.

E. Hints for troubleshooting Multi-probe leaks:

1. Disconnect all multi-probe tubes from instruments. Excessive pressure won't hurt the CNv, but it can easily wreck a Sage vario or a mechanical Airspeed indicator. You can imagine why I stress this!

2. Connect a convenient length of tubing to the open end of ONE tube from the Multi-probe.

3. Cover the matching multi-probe port with wing tape. Don't put the tape end near a static port hole.

3. Use mouth suction and your tongue to create a vacuum and hold it. With the small tubing volume, a very small leak will cause the vacuum to dissipate quickly.

4. Make sure the multi-probe is fully inserted. A very light coating of lubrication is required to avoid damage to critical o-rings. If the leak is from a damaged o-ring, seek professional help and change to fuselage ports until the o-rings can be replaced.