<u>Glider Instruments:</u> (version 2)

Location: Vertical: Altimeter

Earth's Atmosphere

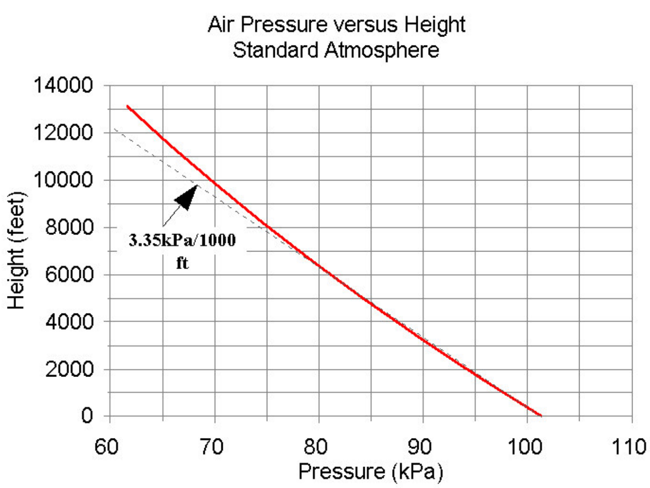
Physical Concepts. **Pressure**
Pressure = Force/Area
[Force = N = kg m/s^2]
[Pressure = N/m^2 = Pascal]
101,300 Pa = pressure of an atmosphere = 14.7 lb/in^2)
enough to lift a column of mercury 29.92 inches or 760 mm.

Physical Concepts. **Density**
water density = 1000 kg/m^3
air density ~ 1 kg/m^3
Relationship (Ideal Gas)
Pressure is proportional to the product of the density and temperature of the gas

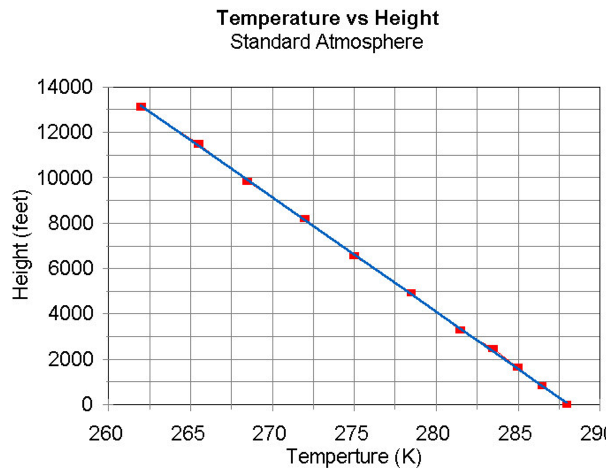
$$P \sim \rho T$$

ρ = density, P = pressure
T = absolute temperature = ^{o}C + 273

Pressure, Density, Temperature versus height

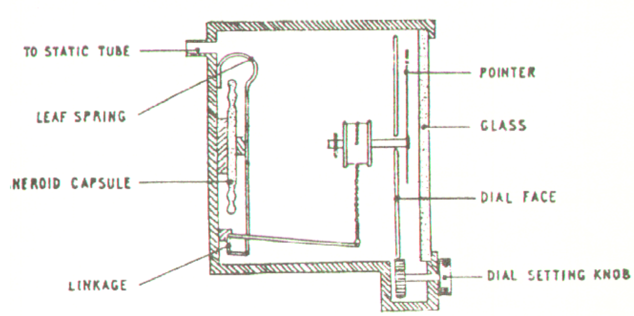


Higher in the atmosphere, there is less air above you so the air pressure decreases. Near the Earth's surface (< 10,000 feet) pressure decreases by about 3.3%/1000 feet. In the same height range the density of air also decreases but by about 3%/1000 feet. The two are not quite the same because the temperature decreases with height and pressure decreases faster than density. At 10,000 feet air pressure is 70% and the density is about 73% of those at sea level. The **temperature** of the atmosphere decreases with height at about 2^{o}C/1000 feet (for a standard atmosphere). This is called the ***lapse rate***. If the actual lapse rate is different from the standard, altimeter calibration will be in error. Corrections can be made from the real lapse rate. Dry air has a lapse rate of 3^{o}C/1000 feet while water vapour saturated air averages about 1.5^{o}C/1000 feet.



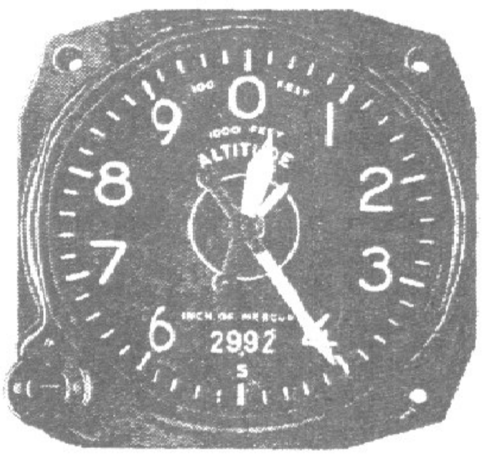
Construction and Corrections

An altimeter measures glider height by utilizing the relationship between the pressure versus height.
In order to measure a change of 100 feet in height the altimeter must be able to measure pressure to 0.3% and better - obviously, it must be a precision instrument. A typical altimeter uses the air pressure from the 'static port' to squeeze a sealed aneroid chamber. Changes in pressure result in a change in the size of the chamber and the resultant movement is mechanically transmitted to a calibrated dial. The dial setting can be offset to compensate for the changing sea level pressure.



Any variation in atmospheric pressure at sea level will cause the altimeter zero calibration to change. Considering the fact that the barometer can go up and down from 29 in (98 kPa) to 30 (101 kPa) to 31 in of Hg (104 kPa). These are variations of 1/30 = 6.7% or equivalent to about 2000 feet in height. It is important to set your altimeter properly before takeoff - either 0 elevation or the actual field elevation (e.g. Stanley airport is 95 feet above sea level). If you are doing more than just local flying, set it for the field height so you have an accurate reference in highlands. An example is the Gore airstrip at 600 feet which if you land there will require that you adjust your circuit altitude up by 505 feet.

The altimeter can also be set using sea level barometer readings. This is not the normal method but in the likely hood that a pilot has a long flight during which a high pressure system arrives, the pressure height might change significantly. A 1/2 inch rise in the barometer would make the altimeter read 500 feet too low. This could be dangerous if the pilot relies only on the altimeter for landing (which a good pilot does not do). A reference barometer at the airport can be used to read the new sea level pressure and this can be radioed to the glider who then can reset the altimeter zero and correct the error.



A typical altimeter dial is shown above and note that there is more than one indicating pointer. The linkage mechanism is built such that one pointer indicates 0 to 1000 feet in one revolution while another will mark the 1000's of feet . A third hand then shows multiples of 10,000 feet. In this fashion the instrument can indicate a large range of altitude with high sensitivity and readability.

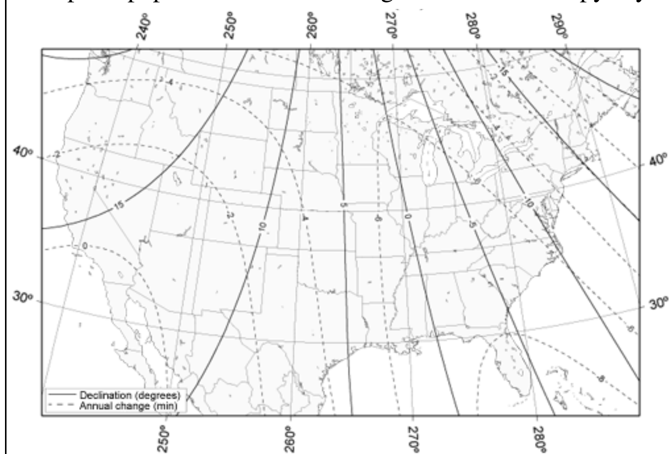
Barograph

This is a clock driven recording altimeter can provide a secure record of height and needed for most badge flights It uses the same principle as the altimeter, but records the altitude on graph paper mounted on a drum that is turning slowly. This enable flights of up to several hours to be recorded. Some global positioning systems (GPS) have a barograph built into them and can record height and time digitally.

Chronometer (Watch)

A **chronometer** or watch is useful and is required on all flights. Flight times are required for glider logs and flight sheets. At Bluenose there are some time limits flights in club glider.

Global Positioning Systems (GPS) have become common in high performance gliders and recently (2000) the price of handheld units are low enough to be economical for many other gliders. These units provide absolute values of latitude, longitude, height, speed, and heading. Their accuracy is limited to 100 m horizontally and 150 m vertically because of military reasons but for general positioning they work well. Most have recording capability and can provide a track of the flight. Special GPS units that can be sealed have been approved by gliding authorities for badge and competition flights. Since GPS units are used more for recording and not active flying, we will not go into them here. (The author has a separte paper on use of GPS in glide - ask for a copy if you are interested).



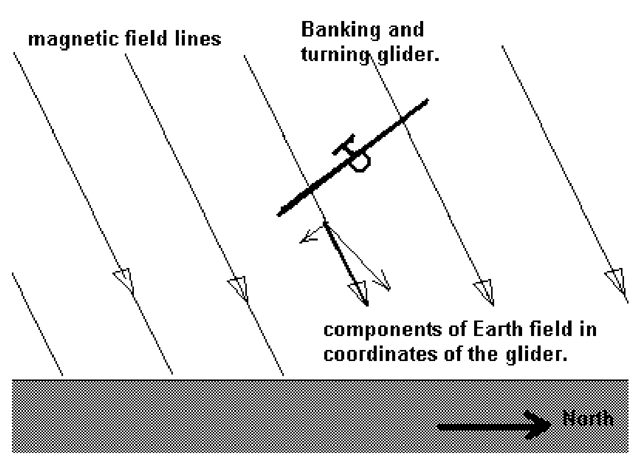
Magnetic Compass: ***Your direction reference***

Properties of Earth's Magnetic Field

<u>Declination and Inclination.</u>

The lines of the magnetic field of the Earth do not align with the true North-South direction. Their deviation varies dramatically with position on the Earth. The above map of North America shows the lines of constant magnetic declination. Here in Nova Scotia the compass needle points about 20 degrees west of true north. Runways are aligned with magnetic north. So runway 27 at Stanley Airport (heading 270°) is not due west but actually heading 250° or 20° south of west. Magnetic declination is not constant and slowly changes from year to year. In Nova Scotia it is decreasing about 5' arc per year. Topographical maps have their magnetic declinations and rate change printed on the margins.

The compass is not used frequently by the glider pilot because we usually fly visual flight rules and use line of sight to determine our flight path. It is necessary and can be useful, however, if a glider is caught in a cloud and has



zero visibility and must maintain a heading so as to not fly in circles.

The compass reacts strangely to turning. The reason for this is that the magnetic field lines are not parallel to the Earth's surface. In fact in our part of the world, they dip severely down at an angle of 70°. The diagram above illustrates an extreme case of the problem. As a glider banks and turns, it will fly east or west with its wings tilted more than 20° to the horizon. The compass will be tilted at the same angle and because of the forces of turning, the 'horizontal' will feel to be parallel to the wings. The compass should point north along one wing. However, at this tilted angle the component of the steeply dipping magnetic field has it 'horizontal' component relative to the glider pulling the compass needle to point along the wing to the south. Hence the compass will read exactly 180° in the wrong direction.

When the glider is heading magnetic north or south it will read correctly but as it turns as shown above, it will swing 180°. As you can image, as the glider goes around in its circle, the compass will swing wildly and be quite unreliable. At times it will swing in the opposite direction that you are turning. To get a proper reading from a magnetic compass, you must fly a straight and level path.

The compass must be aligned periodically. It is affected by changes in location of metal objects in the cockpit and has small adjusting magnets to facilitate alignment (Alignment is called 'swing' the compass).

Velocity and the Airspeed Indicator (ASI):

The horizontal speed of every aircraft is determined using the airspeed indicator which uses the pressure differential between a pitot tube and static port. The static port samples the air pressure at a spot where the airflow past the aircraft is least disturbed and represents the speed of the aircraft. The pitot (ram type) samples the air pressure in a chamber where there is direct connection to the air flow but the air flow is stopped. An expression for

> **Bernoulli's Equation**
> Bernoulli's equation is useful in explaining the operation of the ASI and other glider instruments that operate by air pressure and flow. The pressure, velocity, and density of a fluid at different points along the flow by
>
> $$\mathbf{P + 1/2\ \rho\ V^2 + \rho\ g\ h = constant}$$
>
> P = pressure of the fluid
> ρ = density of the fluid
> V = speed of the fluid
> h = height of the fluid
> g = acceleration of gravity $= 9.8\ m/s^2 = 32\ ft/s^2$

pressure differential between the pitot and the outside can be written using Bernoulli's equation.

Static pressure: $P_{static} + 1/2\ \rho\ V^2 + \rho\ g\ h = const$

Pitot pressure: $P_{pitot} + 1/2\ \rho\ (0)^2 + \rho\ g\ h = const$

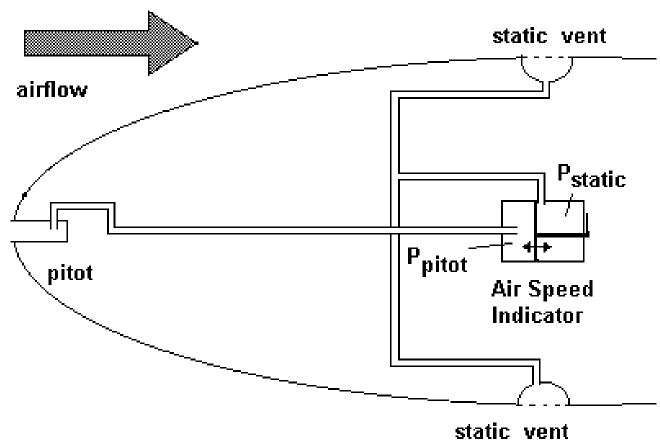
Subtracting these two gives (when the height of both are the same)

$$\mathbf{P_{pitot} - P_{static} = 1/2\ \rho\ V^2}$$

Note that the pressure difference is proportional to the square of the airspeed and proportiona to the density of the air. The dial of the ASI must be properly calibrated to display the velocity of the air past the glider in knots, mi/hr or km/hr. This is Indicated Air Speed (IAS).

As long as the air hits the pitot directly and flows past the static ports the ASI is reliable. However, if glider is slipping through the air this will not be the case and the ASI is not accurate.

Static ports are usually paired on either side of the



glider along the fuselage where the air flow is smooth and undisturbed by the wings or stabilizers. In the Ka gliders, these are on the side ahead of the cockpit halfway up the body. There are two ports to compensate for pressure imbalances that occur when the air impinges on the fuselage at an angle. While the side facing the air flow will have a higher pressure and the other shielded from the air flow will be lower, the sum of the two will tend to average and produce less error in the static pressure.

ASI is calibrated assuming the air density of a standard atmosphere at sea level. As you can see from the relation

$$P_{pitot} - P_{static} = 1/2\ \rho\ V^2$$

if the density is lower (as it is at higher altitudes) the pressure difference will be lower and the IAS will be too low . At lower temperatures and higher density air yields an ASI reading too high but this is not often the case.

The IAS error is not a problem. Air density decreases by about 3%/1000 feet and for a constant velocity the IAS will decrease by that amount. Lift and drag of the aircraft also vary directly with the density of the air and as a result the stall speed is increased. However, because of the low ASI reading, the pilot will flying faster and will be safe from stall.

If, for instance, C-GAWA stalls at 28 knots IAS at sea level, it will continue to stall at 28 knots IAS at all altitudes. The stall speed increase with height but the ASI reads low with height and the two effects exactly cancel.

The same holds for all the other characteristic speeds of the glider including the best glide and sink speeds.

The Variometer : Vertical Airspeed

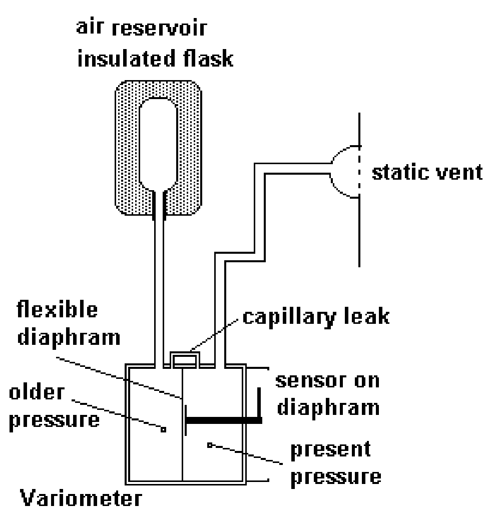
The variometer allows the glider to become a sailplane. It is the most reliable means of finding lift and avoiding sink so as to stay aloft to enjoy the sport. As with the ASI, the variometer works by measuring air pressure.

There are many types of variometers, but they all use the same principle. Record the air pressure, then wait a small interval of time and record the air pressure again. Subtract the two air pressures and if there is a decrease you are increasing in altitude, if there's an increases you are falling.

In fact, computerized variometer work in exactly this fashion. An electrical pressure transducers records the pressure electronically, the pressure is stored in memory, and subtracted from a new pressure measurement moments later. The rate of change of altitude is then calculated by the resident microprocessor which then sends the results to a numerical readout. This type of variometer requires only a static port and does not need the more complicated ports used in more traditional variometers. The computer will use an electronic signal from the airspeed indicator to correct of stick thermals and sink rates of the glider.

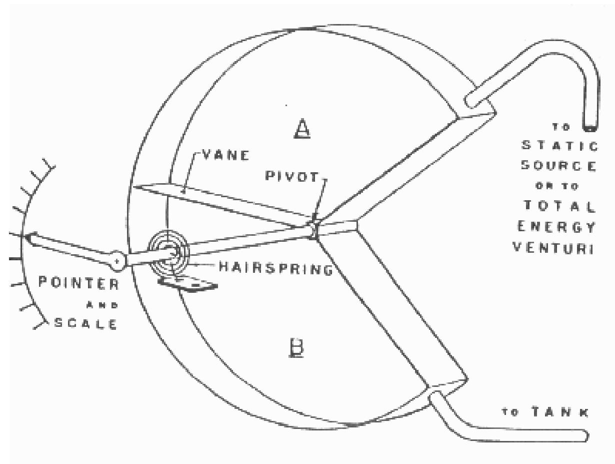
Variometer Mechanisms

Most common variometers are not digital in nature. The all the air at pressure is stored in an insulated reservoir so that the air will not change temperature and hence change pressure in the container. The container is filled and emptied through a small capillary tube leading to the static pressure. The resistance to flow through the capillary causes a pressure difference between outside and inside the container. A flexible diaphragm separates the areas of different pressure and will be deflected by the



difference. When there is no flow, the pressure will be the same on the two sides. Movement of the diaphragm can be indicated through an electrical or mechanical linkage. (e.g. taut band)

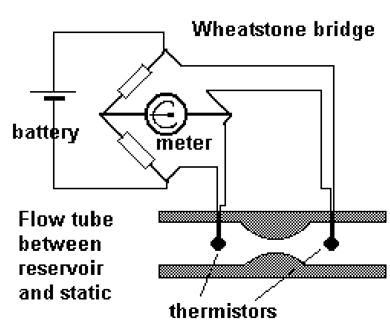
In some mechanical variometer the diaphragm and capillary are replace by a tight fitting vane between the two sides. As shown in the next illustration, an annular volume in this instrument is effectively divided into two parts , "A" and "B" by a very lightweight van mounted on a pivot. When the static air pressure is reduced as in a climb, the pressure in volume "A" will also be reduced, causing the vane to rotate clockwise pushed by the higher pressure in "B". There is leakage around the edge of the vane so



that air flowing from the reservoir into volume "B" will leak into volume "A" and out to the static source. When the climb stops, the pressure in "A" and "B" quickly becomes equalized and the vane, together with the indicating needle, is returned to the original position by means of a hair spring. By use of different hair springs, instruments of different sensitivity can be made. Because of the extremely small mass and lightweight construction of its moving parts the instrument has a very rapid response time and, despite its fine bearings and delicate internal construction it is relatively rugged.

The mechanical variometer is an older design with response times of about 3-4 seconds and while most modern variometers are electronic with better sensitivity and faster response.

In one form of electric variometer, the air flow into and out of the reservoir is measured by its cooling effect on a thermistor. A thermistor changes electrical resistance dramatically as it changes temperature. The usual arrangement is to have the thermistors in a bridge



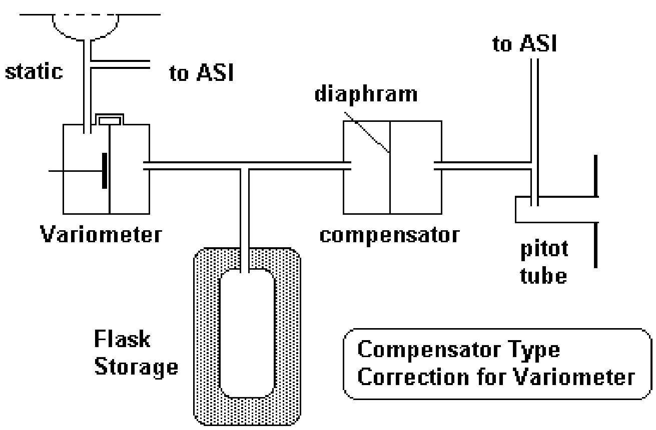
circuit whose balance is upset as one of the thermistor's resistance changes due to cooling in an expanding air flow. The unbalanced bridge is indicated by an electrical meter similar in appearance to that of a mechanical variometer.

A variometer is a very sensitive instrument and can measure 50 feet/minute rise or fall of a glider. The rule of thumb of 3.3 kPa per 1000 feet means that 50 feet/min equals (1/20) 3.3kPa/min = 0.165 kPa/min or about 3 Pa/s. If the response time is1 seconds then the variometer must be able to sense a pressure difference of 3 Pa. (that is 1 part in 30,000 of an atmosphere and equal to the weight of 300g on 1 m^2 or 1/30 gram on 1 cm^2) Paper clip = 1 g.

Total Energy Compensation

Compensator Type

A variometer will read ups or downs as the glider pulls up



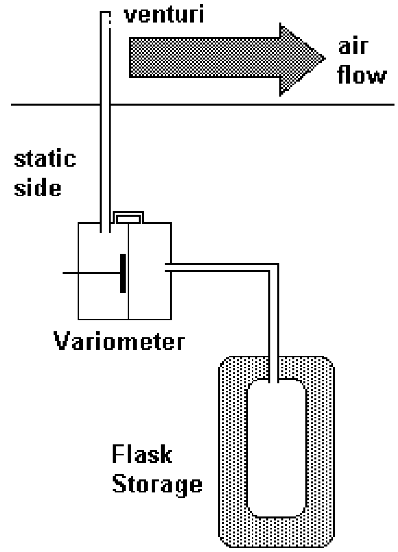
or dives. These actions are an annoyance to the glider pilot who is using the variometer to find thermals and avoid sink and can greatly affect the efficiency of their flying. There are a ways of partially correcting for these 'stick thermals'.

The figure above shows additional connections and devices to utilize the air pressure from the pitot tube to correct the variometer for stick movement. Let's go through an example to illustrate how it works. Consider the case where a pilot is flying fast then pulls up. How does the compensator work?

1. As the plane pulls up it goes higher into lower pressure air at higher altitude.
2. The static side of the variometer would decrease in pressure and its diaphragm would normally be pushed toward that side (indicating positive vertical velocity). However, this does not happen because at the same time.....
3. When the glider pulls up, it decreases in velocity and the pressure in the pitot tube will decrease from what it was at higher speed.
4. This will cause the diaphragm in the compensator to move toward the pitot side and reduce increase the volume and reduce the pressure on the reservoir side of the variometer.
5. If properly balance, this reduced reservoir pressure will match the reduced static pressure.
6 The Variometer reads no change.

The compensator will increase the pressure on the reservoir side it the glider goes into a dive and the variometer will read no change in vertical velocity. This type of compensation is sensitive to changes in static and pitot pressure changes and hence if the glider yaws the variometer can be badly compensated

Constant Energy Tube Type
A compensator which does not use a diaphragm compensator, usually uses a venturi tube for the static side of the variometer and no connection to the pitot tube. One type of venturi is a tube with a hole, slot or two slots on the down wind side of a tube protruding into the airflow. The venturi should be placed in the air stream where it is least disturbed by the glider itself. As the air flows around the tube, a lower pressure is created on the downwind side of



the tube. The higher the airspeed the lower the pressure.

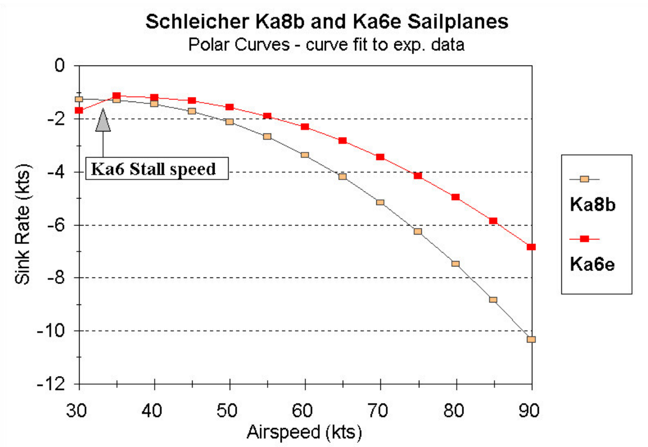
The connections for a venturi tube compensated variometer is shown below. Its operation can be understood by considering what happens during a pull up.
1. As the glider pulls up and gains height the static air pressure decreases.
2. The glider also slows at a smaller glide angle.
3. Slower speeds past the venturi means a higher pressure at the venturi holes.
4. The venturi must be built so that the increase in its pressure nearly compensates the decrease in static pressure and the variometer sees no change.

On stick down and increase glide angle the air speed increases, the altitude decreases faster and the pressure increases. But the decrease in pressure at the venturi holes compensate and again the variometer is unaffected.

If however, the glider flies into a thermal its airspeed will not change but the glider will be rising. The pressure at the venturi will be decreasing and the variometer will indicated a positive vertical air speed.

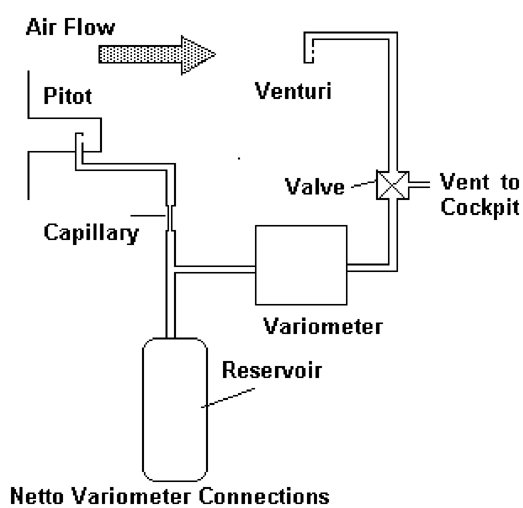
The best location of the Total Energy (TE) tube is mounted on and in front of the vertical stabilizer high above the fuselage. Some TE tubes are placed on the nose of the aircraft or on and above the fuselage behind the cockpit . The TE compensator does not correct for the sink rate of the glider. As the speed of a glider increases, its sink rate will increases and that will be indicated on the TE compensated variometer. There are additional connections that will allow remove of this last variation.

The Netto or Air Mass Variometer



The sink rate of a glider generally increases with airspeed. These relationship vary approximately quadratically with airspeed as you can see in the graphs (called polars) shown below.

As you will remember, the pressure from the pitot relative to the static pressure varies with the square of the airspeed. The netto uses this fact to as-nearly-as-possible cancel out the affects of the sink rate on the variometer. As the velocity increases sink rate increases (the glider is dropping in altitude faster) and the rate of pressure increase on the venturi increases. This increase in pressure on the venturi side can be compensated with a little bit of added pressure from the pitot. A connection is made from



Netto Variometer Connections

the pitot to the reservoir side of the variometer through a capillary tube. This tube must be selected to just compensate for the increased sink due to increased air speed. A diagram of the typical connection is shown below.

Example: Ka6e Data

Sink rate at 45 knots = 1.4 knots

140 feet/min --> 0.46 kPa/min

Sink rate at 60 knots = 2.4 knots

240 feet/min --> 0.79 kPa/min

Ratio of velocity squared

$(60kts/45kts)^2 = 1.8$

Ratio of pressure changes

(0.79kPa)/(0.46kPa) = 1.7

Since the pitot pressure and altitude pressure are changing at the same rate the pitot connection should compensate the variometer for glider sink rate - it will then read the air mass movement vertically.

The netto variometer, is particularly useful for detecting small thermal when travelling at high speed between thermals. Without a netto variometer, the large sink rate at higher speed masks the small thermals.

In the diagram above, an extra valve has been added on the venturi side. This is for emergency purposes. Normally the venturi is connected to the variometer, but if the venturi is damages, clogged, or lost then the variometer would not function in a useful manner. The valve should be accessible to the pilot and opens to the static pressure of the cockpit. This will allow the variometer to work and give reasonable readings although without the contact energy corrections.

The Yaw String -

When Wilber and Orville Wright were discussing the crucial lateral control of their gliders, they decided a rudder was absolutely necessary. Wilbur is suppose to have said something like: " Yes, and to tell when to apply this new control and to tell how much to apply, we will install a short piece of string out front where we can see it. This string will tell us all we need to know!" -- Wilber had just invented the yaw string - the first aircraft instrument .

Care of Instruments

Sticking of Instruments - All dial instruments have delicate mechanical mechanisms that stick slight and lag in their reading. Tap on the instrument panel beside the instrument to loosen the mechanism and update the reading. Do not strike the glass of the meter.

Checking Airspeed Indicator - Do no blow into the pitot tube or you might do damage to the altimeter.

The yaw string is a rugged instrument but must be in the right spot and renewed when worn out. Always check that it is untangled before launching.

Power - Most electrical instruments, as well as the radio, are powered by 12 volt storage batteries (13.8 volts).

These should be treated properly to ensure long life. Turn off instrument power when the glider is unused on the ground. Remove the battery and put it on trickle charge until needed again.

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Larry Bogan --March 2, 1999/ revised Mar 2000